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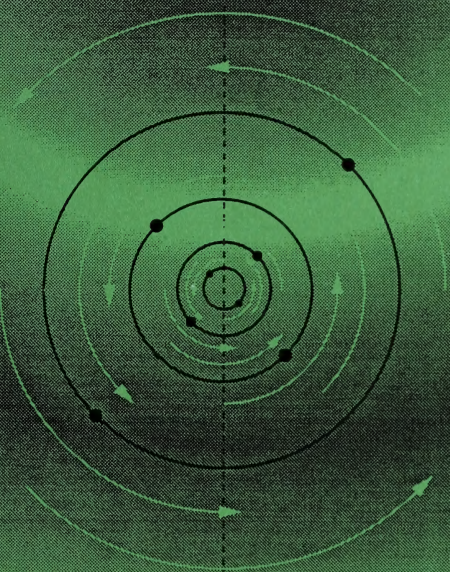
UTILIZATION GUIDE

Science



TECHNOLOGY & SOCIETY

Science, Technology and Society

BPN 3539-01 *The All Weather Video*
3539-02 *Toxic Wastes: A Problem in Search of a Solution*
3539-03 *The Lowdown on Additives*
3539-04 *Extreme Close-up*
3539-05 *After the Flush, Part I*
3539-06 *After the Flush, Part II*
3539-07 *No Lab Coats Required*

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The Science, Technology and Society Series

STS is an international science education movement. It represents the first significant change in the science curriculum in 25 years. The STS concept strives to broaden the scope of science education by integrating into science curricula accurate presentations of the nature of science, the nature of technology and the interactions of science and technology with each other and society. The video series provides illustrative examples of the relationships between science, technology and society.

The STS connections describe products and processes; environmental and ethical issues relating to the interrelationships among science, technology and society; how scientific knowledge develops and the influence of society on scientific and technological research; and science and technology related careers. The contexts are meant to be relevant to students' lives and also prepare students for life in a rapidly changing society in which science and technology play an important role.

Science Technology & Society

The All Weather Video

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The All Weather Video

To the Teacher

This video program is intended for use in first year high school (Science 10) as an introduction to a study of weather or as an end of unit activity. The purpose is to show how science and technology, along with human expertise, are applied in meteorology. More specifically, the video program is intended to:

- explain how the sun's energy is the force behind weather
- describe air masses and associated cyclonic weather phenomena
- identify the technology used in forecasting weather
- foster an appreciation of the importance and the complexity of weather forecasting.

This program examines the processes that cause the weather we experience and that are used to predict it. Another thread running through the video is the importance of accurately predicting severe weather. Although climate is touched upon briefly, the main focus of the program is weather and the technological network that is in place to predict it.

Overview of The All Weather Video

The video begins as host Bill Matheson, a professional weather forecaster, looks at global sized phenomena and briefly mentions some climate types. Then the program focusses on regional

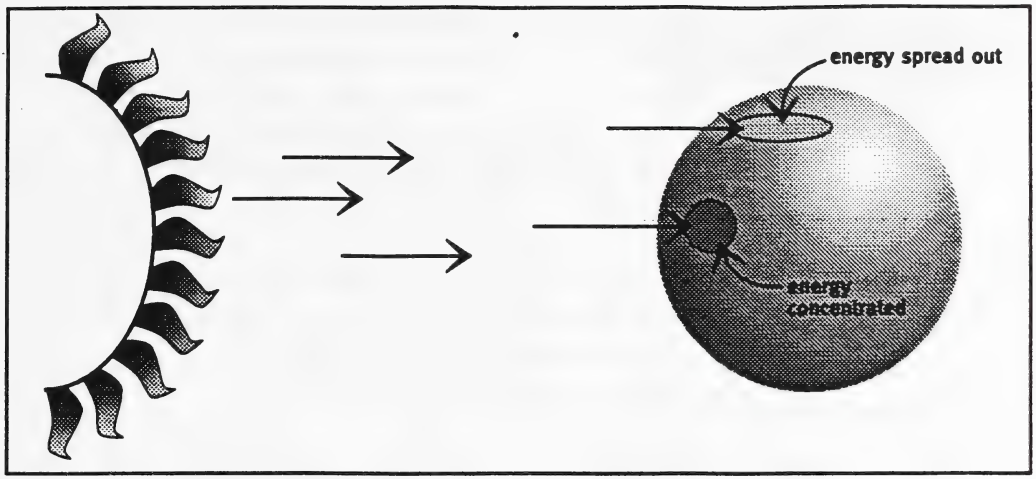
phenomena in the cyclonic zone of the Earth, examining and tracking the progression of a cyclone or low pressure system. Finally, local phenomena are discussed, with an emphasis on severe weather, including hurricanes, thunderstorms, and tornadoes.

The technology used to predict these phenomena is focussed upon throughout most of the program. The radiosonde, weather satellites, and weather radar (including Doppler radar) are shown, as well as the standard measurement instruments.

Climate and weather are the combined effects of air pressure, temperature, relative humidity, winds, and precipitation. Day to day changes in these factors are described as **weather**, while **climate** is the average of the weather conditions over several years at some locale.

The sun heats the equator more than the poles. When a temperature gradient is established heat must move from hot to cold. (This is a statement of the second law of thermodynamics.) These two effects taken together set the atmosphere and the oceans into motion. The motion results as heat is transferred from the equatorial to the polar regions of the Earth by convection, producing winds and ocean currents.

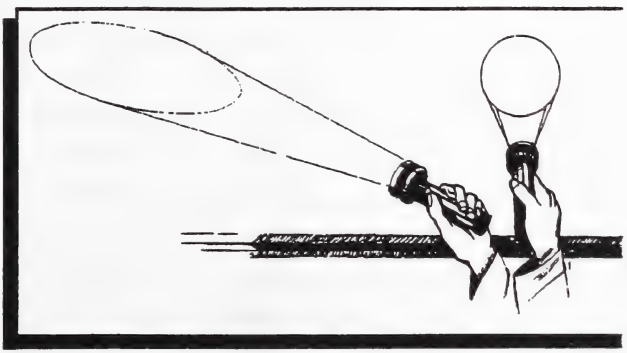
The temperature difference between equator and poles is caused by the angle at which the sun's rays strike the Earth's surface. When a source of radiation hits a surface at an oblique angle its energy is spread out over a greater area than it would cover if it hit the surface at a right angle.



Demonstration

Shine a flashlight onto a blackboard so that the light beam hits the blackboard at a right angle. Draw a chalk line around the circle of light on the blackboard. Repeat this procedure with the flashlight shining at some other angle. (Be sure to keep the flashlight-to-blackboard distance constant. It is easy to show that the second area is larger than the first one.

The same energy is spread out more so each unit square of lit up blackboard gets less radiant energy. When this concept is applied to the Earth it explains why the equatorial regions are the hottest. The Earth's axis is tilted 23.5°, so the place on the Earth that receives the sun's direct rays (known as the ***heat equator****) moves from the Tropic of Cancer on the Summer Solstice to the Tropic of Capricorn on the Winter Solstice. In this program and guide, "equator" refers to the heat equator.*



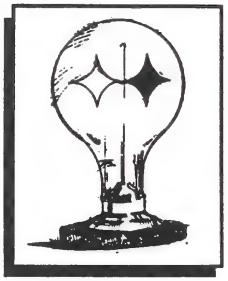
Student Lab

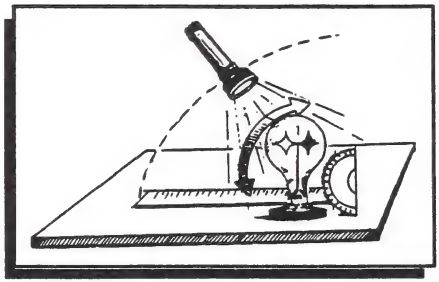
Purpose: *To show the effect of different angles on the strength of radiation.*

Design: *Shine a light on a radiometer at various angles to the plane of the vanes and count how many turns it makes in a certain time period. The distance from the radiometer to the light should be held constant.*

Notes:

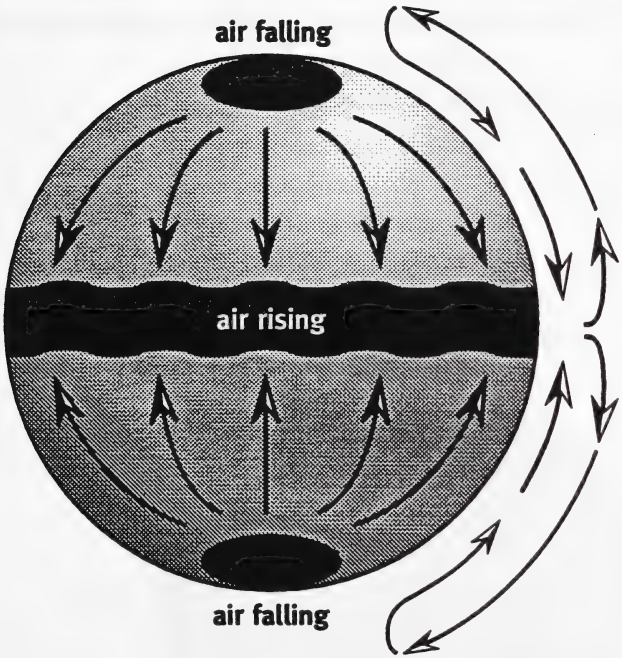
1. *A radiometer is a device that has vanes that spin in proportion to the radiant energy that hits them. They can be obtained through the science supply companies or in most stores that sell science toys. They cost about $15 retail (1993 price) and they have an explanation of how they work printed on the box.*





2. *This lab can be used to work on graphing skills, especially drawing the line of best fit. The data points usually have some scatter to them but the overall trend is that smaller angles (light beam to the surface of the vanes) produce a slower rate of turn of the vanes (90° perpendicular to the plane of the vanes is the "equator" and 0° parallel to the plane of the vanes is the "north pole").*

The experiment, applied to world climate, shows that **latitude** is an important climatic factor. It may very well be the most important climatic factor of all. If latitude were the only factor affecting climate the Earth's atmosphere might move in the way this simple model suggests.



This model predicts that a belt of calm air should exist at the equator (the air is only rising), and that regions of calm air should also exist at the poles (the air is falling). Between these locations the winds should blow from the poles to the equator.

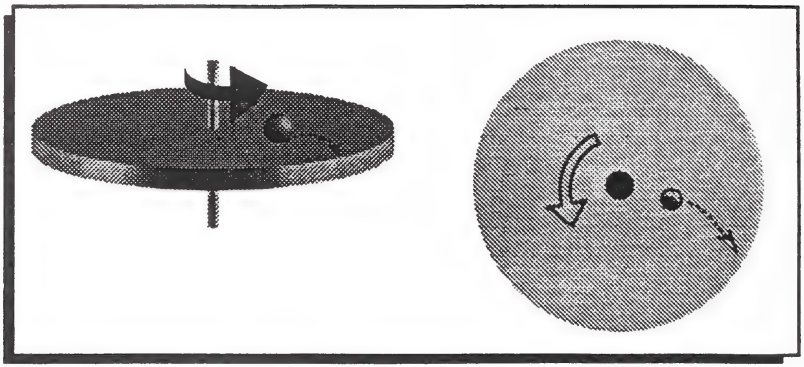
In fact, the winds do no such thing! The model must be missing some other important factors.

The missing factor in the previous model is the **Earth's rotation**. Imagine a rotating platform (like a merry-go-round). An object travelling on it experiences forces that tend to push the object off the rotating platform. The "forces" seem do two things:

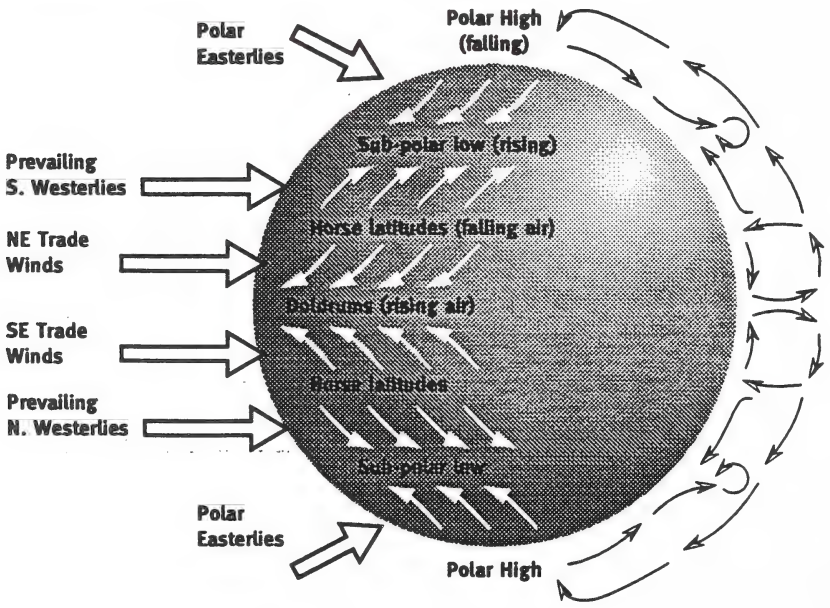
1. Push the object away from the centre of rotation (the **centrifugal force**).
2. Deflect the object sideways as it moves outward (the **coriolis force**).

An object on a rotating surface will move in a curved trajectory

outwards from the centre of the rotation *relative to the surface.*



The coriolis force, when applied to the winds on the Earth, a rotating surface, deflect to the right in the northern hemisphere and to the left in the southern hemisphere. The rate of rotation determines how much they deflect. Adding the coriolis force to the model produces a very different picture.



This model is about sixty years old and is found in all the textbooks. It comes much closer to what is observed but has shortcomings of its own. The predicted windy and calm belts do not appear except over water. The trade winds do appear where predicted except in the Indian Ocean. This model might work on a planet completely covered by water but the presence of land masses must also be included in any serious attempt to model world climate.

Jupiter and Saturn are fluid covered planets and their surfaces do display the banded structures predicted by this model. They have more convection cells because they rotate much faster than the Earth does and the coriolis force is greater.

By the 1970's a great deal had been discovered about the upper levels of the troposphere (the bottom layer of the atmosphere where the weather occurs). Even today the workings of this part of the atmosphere are not well understood but they do play an important role in the Earth's climates.

Layers of the Atmosphere

Standard diagram in any earth science text.

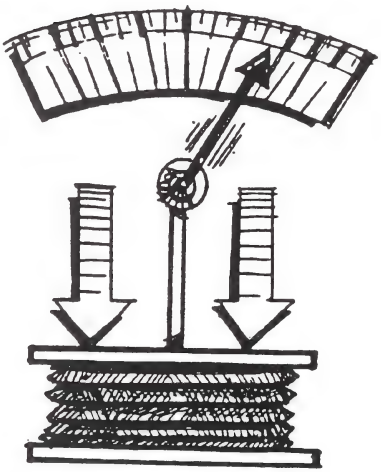
The **jet streams** are tubes of extremely fast winds that race around above the middle third of the planet in a zigzag fashion. When they move toward the equator they also lose altitude and when they move pole-ward they gain altitude. They transfer heat from tropical to arctic areas and influence the direction of surface weather beneath them.

The air above us has weight and exerts a force on everything on the Earth. The pressure (force per unit area) associated with this force is the **air pressure** or **atmospheric pressure**. Its value is dependent upon local conditions (such as altitude). Standard air pressure is equal to:

- 101.3 kPa
- 76mm of mercury (29.92 inches of mercury)
- 14.7 psi (pounds per square inch)

Air pressure is measured with a **barometer**. The type found in most small weather stations is an **aneroid** barometer.

Aneroid Barometer

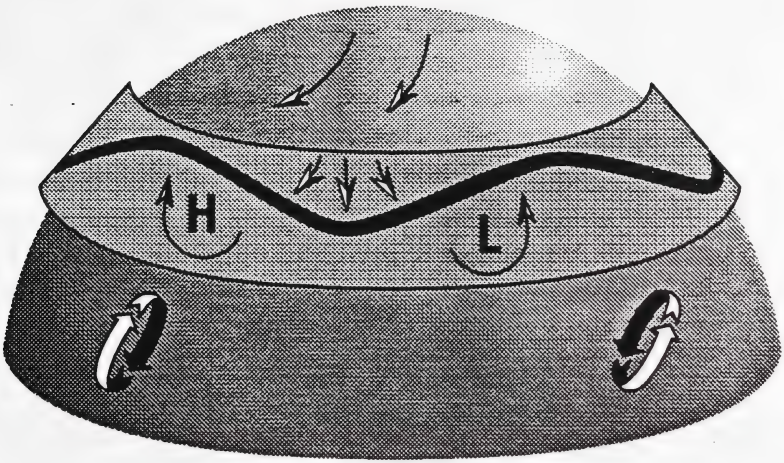


High pressure squeezes bellows in and pulls needle to "HIGH."

Low pressure lets bellows out and pushes needle to "LOW."

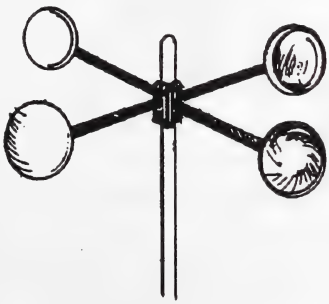
When air rises its pressure drops, producing a **low pressure centre**. When air descends its pressure increases, producing a **high pressure centre**. Jet streams therefore create highs as they move toward the equator and lows as they move pole-ward.

Here is a model that includes the jet streams.



This model comes even closer to the actual global wind patterns.

Wind speed is measured with an **anemometer**; wind direction with a **weather** *vane*.

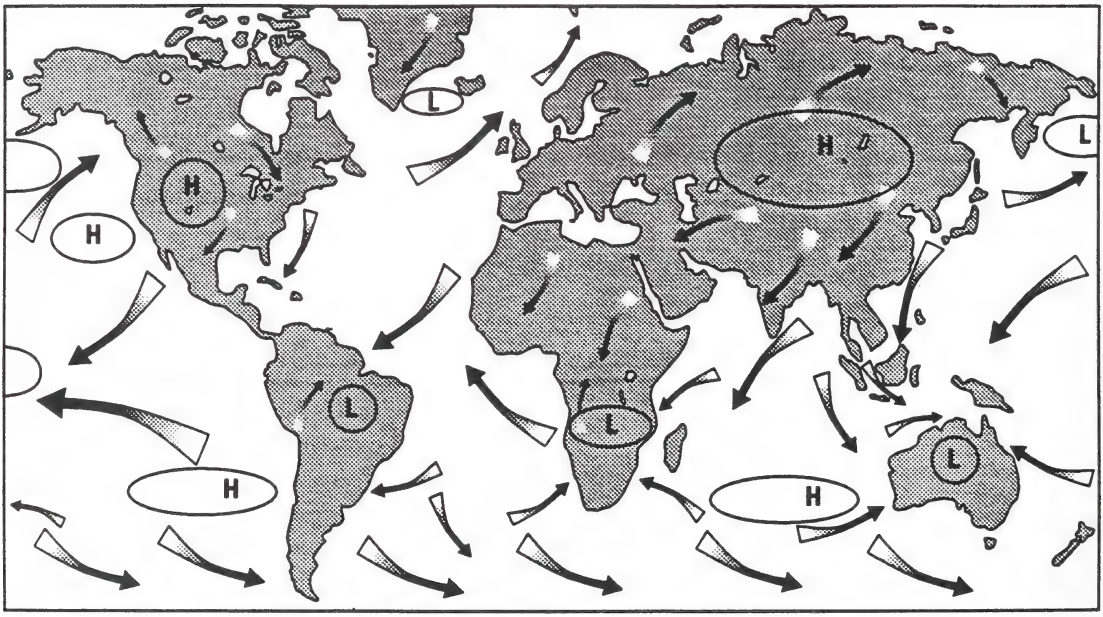


A spinning anemometer turns a cable hooked to a scale below.

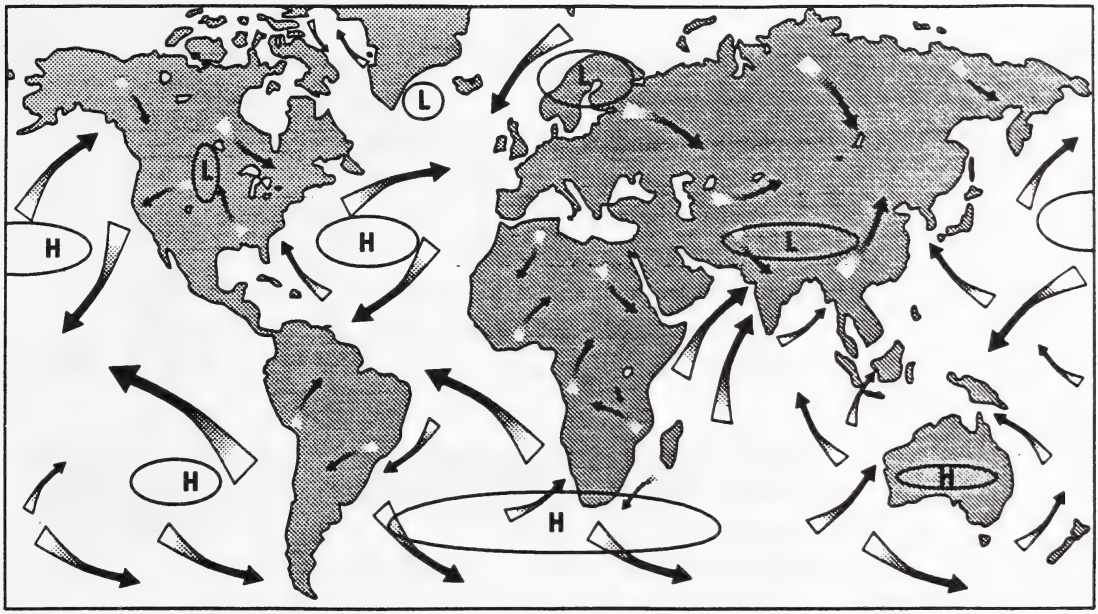
Student Project

Look in an atlas and find the actual pattern of global winds. Compare these to those predicted by the second and third models. Discuss which model works best and where the models break down.

Here are the maps of where the Earth's winds actually do blow (on average). The reason for two maps is, again, that the tilt of the Earth's axis moves the heat equator throughout the year.



Earth — Pressure and Winds
January



Earth — Pressure and Winds
July

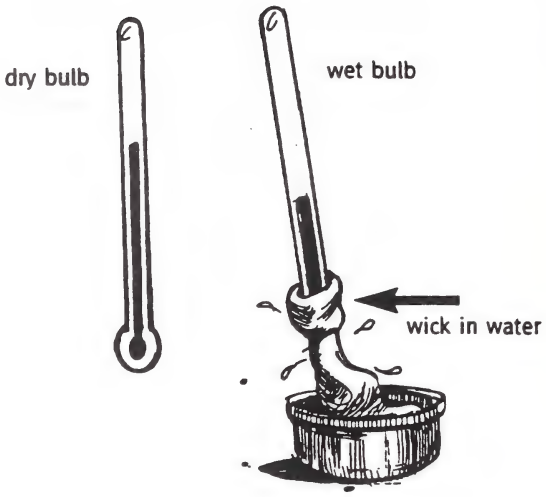
The atmosphere is a chaotic system and the winds shown in these maps don't show the smaller scale movements that are always present as well. Large "blobs" of air covering thousands of square kilometres of surface sometimes stop for days or weeks. These are called *air masses* and they gradually take on the temperature and humidity characteristics of the Earth below them. Air masses are named according to the location where they were formed. **Continental** air masses form over land and **maritime** air masses form over water. In addition, they are classified as **tropical**, **arctic**, or **polar**.

Nearness to and direction from large bodies of water is another of the major factors that determines climate. If a maritime air mass were to move inland it would probably cause that land to have a lot of precipitation. A continental air mass brings drier conditions.

Warm air can hold more moisture than cold air can. If the actual amount of water in the air is compared to the maximum amount of water the air can hold at that particular temperature the result is the **relative humidity** (or **RH**). The RH is expressed as a percent.

$$RH = \frac{\text{actual amount of moisture}}{\text{maximum amount of moisture}} \times 100$$

RH is measured with a **hygrometer**. One kind of **hygrometer, a sling psychrometer,** uses the rate of evaporation to determine the RH.



The lower the RH, the more evaporation that occurs on the wet bulb and its temperature is therefore lower.

A chart of dry bulb temperature and wet bulb temperature is read to obtain the RH.

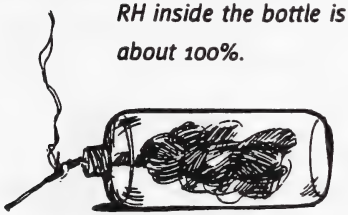
When air rises it expands and cools. As it cools its RH increases. This occurs because the actual moisture content of the air stays constant while the maximum amount that can be held drops. The fraction's value increases. If air continues to

rise, eventually its RH will reach 100% and the water vapour will condense into water droplets or sublime into ice crystals. In either case clouds will form. The temperature at which the RH reaches 100% is called the **dew point**.

The opposite of this occurs when air falls. It compresses and warms up. The RH falls and any clouds are likely to disappear as the water evaporates.

Demonstration

1. *Partly fill a plastic pop bottle with water, swish it around and empty it. The RH inside the bottle is now about 100%.*



2. *Light a match, hold it near the bottle mouth and blow it out. Direct the smoke into the bottle. This provides condensation nuclei for the water molecules to condense on.*
3. *Blow into the bottle as if you were trying to blow it up like a balloon and suddenly release your mouth. A cloud will appear in the bottle! It looks like a tiny bit of fog in the bottle. Fog is, in fact, a cloud at ground level.*
4. *Blow again. The cloud disappears as the pressure increases.*

High and low pressure centres are major climatic factors. A climate dominated by low pressure will be cloudy and wet. The world's rain forests are examples of such climates. Climates dominated by high pressure will be sunny and dry. The world's great deserts are examples of these climates.

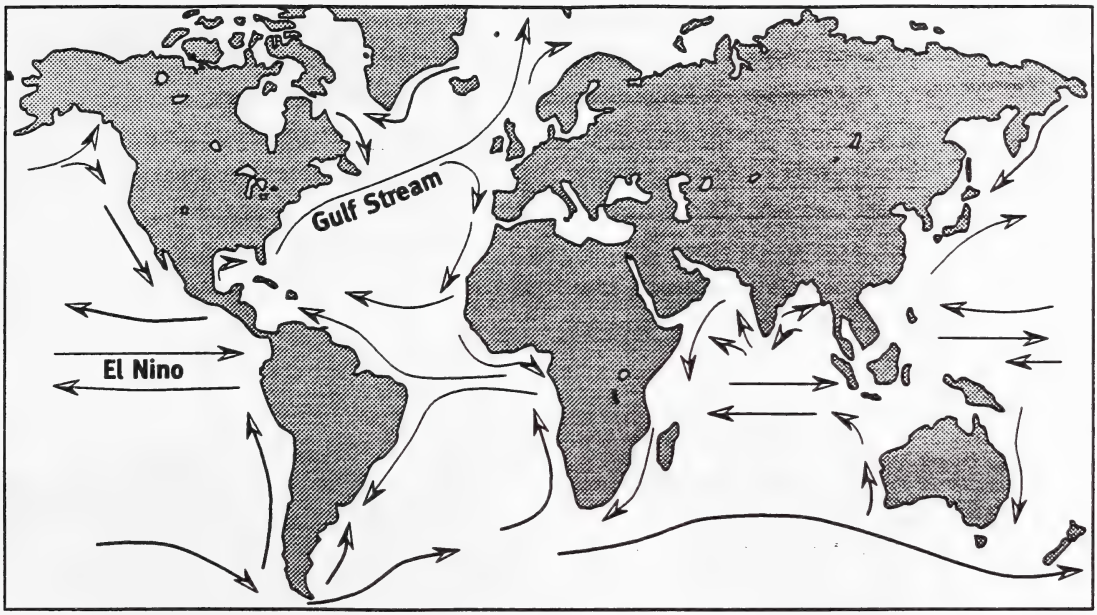
Mountains cause this effect as well, although on a smaller scale. As air rises to go over a mountain it loses moisture. Once over the top, the air descends and heats up. Places on the windward side of a mountain will have wet climates while those on the leeward side will be desert-like. This is called the **rain shadow effect**. Chinooks are very warm and dry winds that form as air falls down the eastern slopes of the Rocky Mountains in southern Alberta. **Nearness to mountains** is another climatic effect, although somewhat localised.

The higher up you go, the colder it is. This is because the Earth's surface is heated by the ground. **Altitude** also influences climate.

Lastly, the **ground cover** can influence climate. This is the way in which climate was first changed by people in a drastic way. Two thousand years ago, Carthage, now North Africa, was a lush farming area. The Romans sowed salt into the soil of the enemy city and the area is still a desert today. Once the plants were gone there was nothing to prevent the desert from claiming the area.

Ocean currents

The water of the oceans is also moving in convective loops called ocean currents. Warm water from the tropics loops pole-ward carrying enormous quantities of heat with it. The routes of these currents depend upon the positions of the continents, so there is a tectonic influence as well.



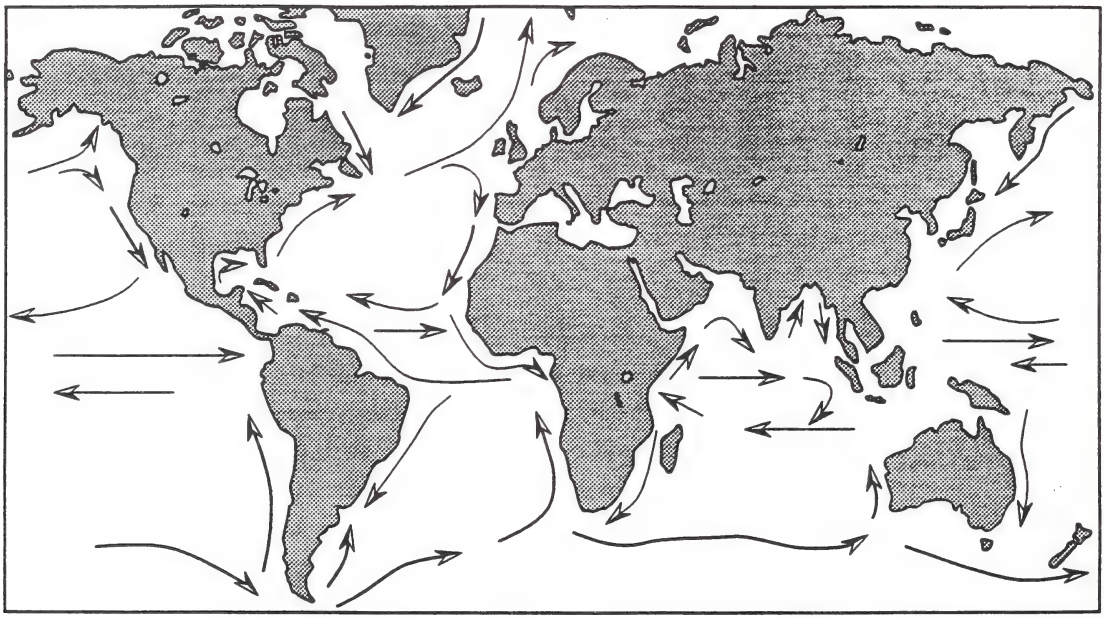
Earth — World Ocean Currents
January

There are also ocean currents that circulate deep below the surface. One such current, called the Atlantic conveyer, circulates over much of the world. It is powered by the formation of streams of moving deep water south of Greenland. As water flows northward along the Gulf Stream it cools, contracts and becomes more dense. Its salinity increases as evaporation occurs, also increasing its density. The density reaches a point where the water sinks through the less dense layers of water below, and the cold, salty water returns southward near the ocean bottom.

The Gulf Stream carries warm water much farther north than occurs anywhere else on Earth. As a result Europe is about 8°C warmer than it should be!

The flow of warm water from the western to the eastern Pacific Ocean is the Equatorial Counter-current. It varies in strength in a semi-regular fashion. When it is particularly strong the warm water it carries overrides the cold water that sits off the coast of Peru.

This effect is *El Nino* and when it occurs a strong ridge of high pressure sets up over western British Columbia, which sends the jet stream far to the north. The weather in the northern hemisphere becomes unpredictable or abnormal when El Nino is active.



Earth — World Ocean Currents
July

Student Project

1. *Have the students look at the maps of global winds and predict climate for different regions.*

    - *What places always have low pressure? high pressure?*
    - *What places have low pressure for half of the year?*
    - *Look for places where the spiralling wind patterns around lows and highs would bring maritime air to a location (or continental air).*
    - *Where should tropical rain forests be located?*
    - *Where should deserts be located? (Don't forget the mountains.)*
    - *Should Vancouver or Halifax be wetter? Why?*
    - *Should Edmonton or London, England, be hotter? Why?*

    These are just a few possible questions. Many others are possible.

2. *Have the class prepare climate graphs of cities all around the world, including latitude, longitude and altitude for each. Students could each produce one or two. In groups, students could control climate factors and compare similar locations.*

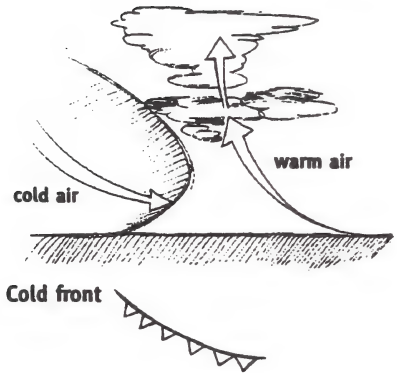
    - *Do all places with the same latitude have similar climates?*
    - *Do all places with similar latitude and altitude have similar climates?*

    Alternatively, have students group cities into those with similar climate types and look for reasons why they might be similar.

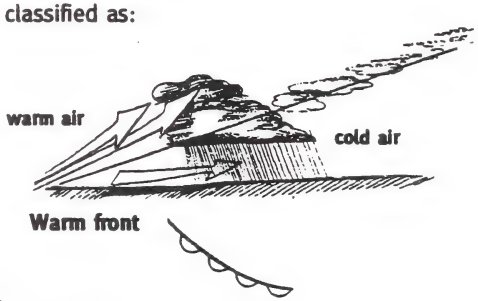
    Look for exceptions to the rules and try to find the reason(s) for the exceptions. Reykjavik, Iceland comes to mind.

Weather

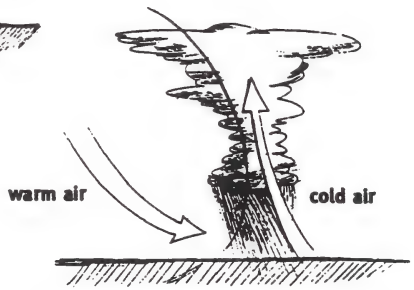
Weather is more variable than climate but it is determined in the same ways. When air masses move around they contact and push on each other. Two air masses that have different characteristics do not mix easily. It may take days or weeks for a moving air mass to mix with its new surroundings. When air masses touch, the boundary between them is called a **front**. Fronts are classified as:



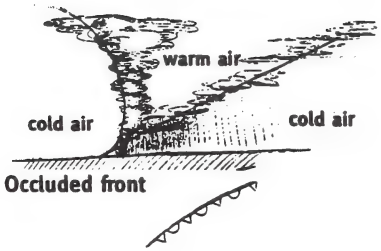
Cold front



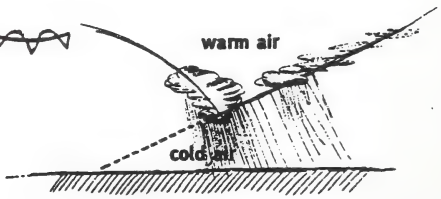
Warm front



Stationary front



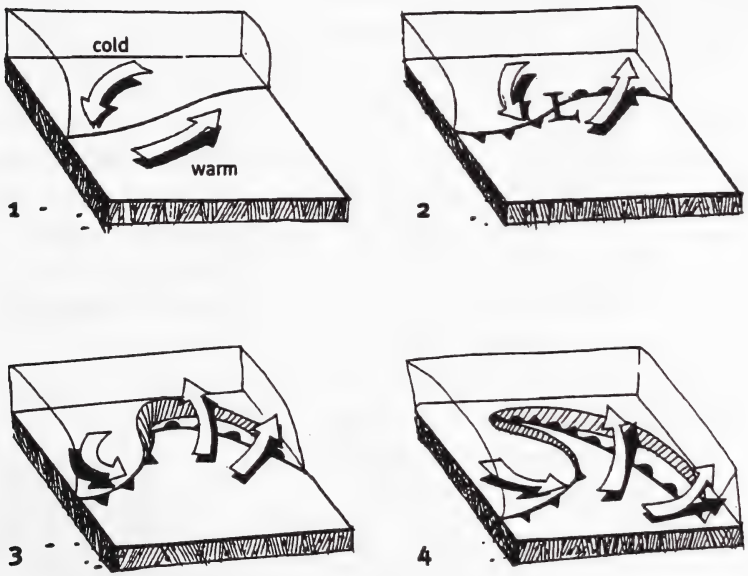
Occluded front

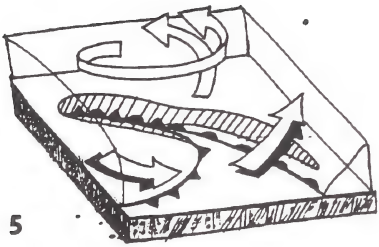


Upper front or trowal
Trough of warm air aloft

When fronts are moving through a locale they tend to cause some kind of precipitation and winds. Much of the weather of Canada and the U.S. is caused by fronts associated with **cyclones**. A cyclone is a low pressure centre and its attendant winds. (It is not a tornado.)

When air rises to produce a low pressure centre a partial vacuum is produced. Air nearby rushes in to replace the risen air (winds). These winds spiral counterclockwise in toward the pressure centre as a result of the coriolis force. Cooler air advances southward on one side of the centre while warm air advances northward on the other side. Here is the progression of a typical cyclone.





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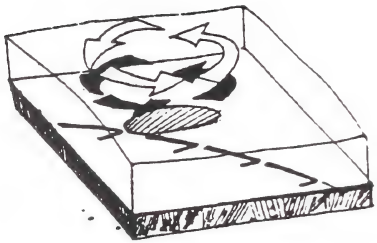

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Precipitation often occurs when no fronts are in a vicinity. Waves of cold air left over from other systems can be moving across the sky at high altitude, influenced by the jet streams. If warm air rises and hits the cold air aloft large clouds associated with storms result. After a bout of cold temperatures, a location often experiences afternoon showers on warm sunny days. This happens because the air aloft is so cold that the updrafts caused by heating air produce extra tall clouds. Air with such a large temperature gradient is termed **unstable**.

Student Lab

Cut out the weather map from the local newspaper each day for a period of about one week. Relate the details on the maps to the weather experienced during the same period of time.

Choosing a time of changeable weather will probably include cyclonic activity. Try to identify a cyclone in the set of maps.

Severe Weather

Complex convection at a smaller scale occurs within the

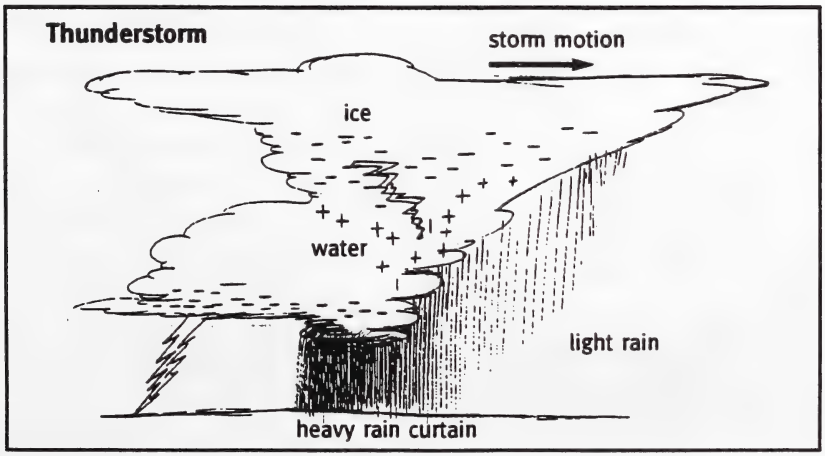
overall convection of a low pressure system. Near a cold front the vertical speed of the rising air is extreme. This strong vertical convection produces clouds that start at 2000 metres and grow from 10 to 16 kilometres high! These are **cumulonimbus** clouds, which are responsible for such things as heavy rain, hail, thunderstorms, tornadoes and hurricanes.

These clouds serve another purpose or two as well. Water vapour contains a huge amount of latent heat (2268 J/g). This heat is carried to the top parts of the troposphere and released there when the water vapour condenses. These clouds act as immense heat pumps!

With over 100 lightning strikes per second, the Earth acts like a huge electric capacitor that is constantly charging and discharging. The lightning helps to fix nitrogen into the soil, producing nutrition for plants.

Thunderstorms

Ice crystals and water droplets build up opposite electric charges when they rub together. Large positive and negative charges collect in various places in the cloud.



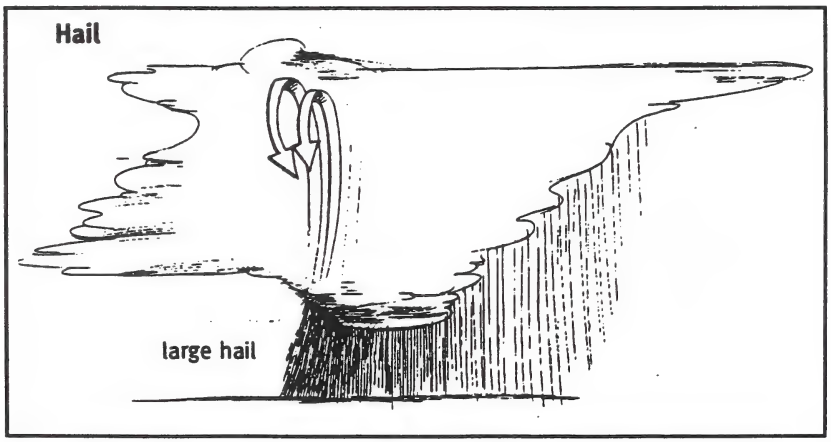
Thunderstorms occur when giant sparks of electricity move from one part of the cloud to another, from one cloud to another, or from a cloud to the ground as these discharge. Lightning's temperature is 40,000°C! It heats the air around it so much that the air expands away from the lightning at supersonic speed. This results in a sonic boom called thunder.

Hail

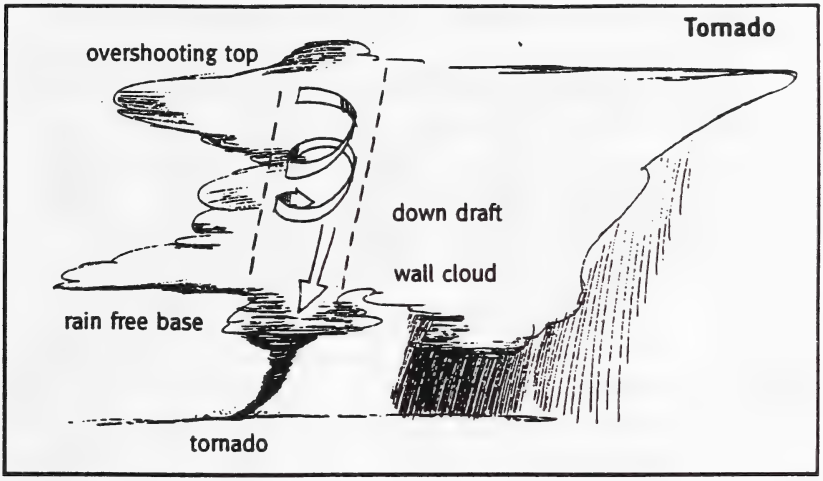
Hail occurs if the updrafts in the cloud are strong enough to hold very heavy, ice covered raindrops in the cloud and toss them around. They get layers of water and ice crystals added to them until they are heavy enough to fall. The largest recorded hailstone was the size of a grapefruit!

Tornadoes

Tornadoes produce the strongest winds of any type of storm. It takes a large cumulonimbus cloud with well organised downdrafts in it to produce a tornado. The storm's updrafts and downdrafts combine in a still poorly understood way to produce a rotating column within the cloud. This produces a rotating wall of cloud which can tighten and push down toward the



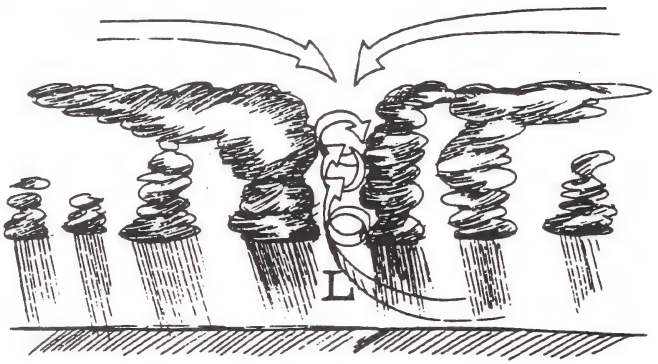
ground (the **funnel**). When the funnel reaches the ground it is called a tornado. Winds of up to 500 km/h can be produced.



Hurricanes

Hurricanes are the largest storms on Earth. They are organised cyclones hundreds of kilometres in diameter that contain bands of rainstorms that increase in intensity toward the centre of the storm. The low pressure centre, the **eye**, begins the storm by elevating warm moist air. Hurricanes can only form over water that is at least 26°C. The temperature of the water ensures a great deal of

Cross section of a Hurricane



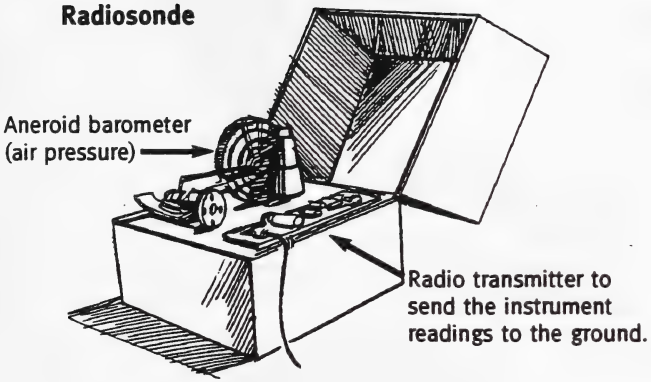
evaporation and when this huge amount of water vapour condenses in the upper parts of the storm the released latent heat provides the energy needed to build the storm's intensity. Hurricanes live until they move over land or over colder water—often for weeks. The wall at the centre is a connected set of cumulonimbus clouds with heavy rains and winds of up to 150km/h. Under the eye of the storm it is sunny and dead calm—with the prospect of renewed violence at the other side of the wall!

Meteorologists use peoples' names to identify hurricanes. Boys' and girls' names are assigned to the storms in alphabetical order. (The first storm of the year will have an "A" name and so on.) The list of the names to be used is published a year in advance.

A great deal has been learned about weather in the last few decades. **Radiosondes** are sent up in weather balloons to measure temperature, air pressure, relative humidity, wind speed and wind direction twice a day, every day, from 300 locations. Meteorologists track these instruments with radio equipment and add their data to the surface data in order to make the weather forecasts.

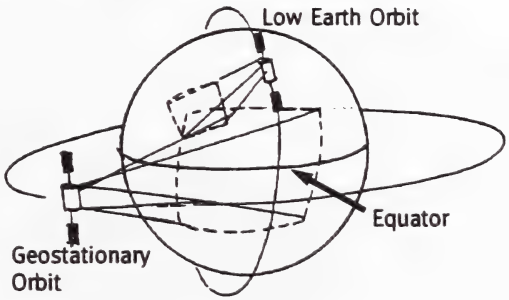
When radiosondes fall back to Earth they are not reused. Most crash land and are destroyed upon impact. The ones launched in populated areas have parachutes to protect the people below.

Radiosonde



*Thermistor for temperature and *Hygristor for RH

Weather satellites take pictures of the atmosphere from above and show large and medium scale systems that might be missed otherwise. Some orbit high enough above the Earth that they take 24 hours to complete one trip around it and therefore stay above one place all the time. Such a satellite it said to be **geostationary**. Geostationary satellites are placed over the equator and can see almost half the Earth at a time. Other satellites get around in about 90 minutes in lower orbits. These satellites see smaller areas but can take more detailed pictures.

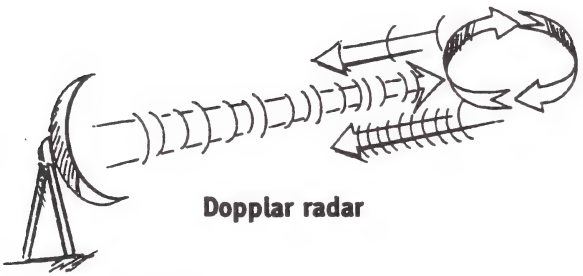


Another new technology being used is **radar** (radio, detecting and ranging). Radio waves will bounce off large rain drops in clouds, so a radar beam can detect those clouds that might harbour severe rain. **Doppler radar** is the latest piece of equipment in the meteorologist's arsenal. When radar beams reflect off raindrops that are moving

*Devices that convert what they sense into variable voltages

towards or away from them the beam frequency changes. The frequency goes up if the raindrops are approaching the incident beam and it goes down if they are receding from the beam. This shows as a colour shift on the screen. Spiralling winds in a cloud, the precursors of tornadoes, are detected with Doppler radar.

atmospheric conditions at one time cause huge differences in conditions later on. Meteorologists can predict conditions 24 hours in advance accurately most of the time. The five day forcast is still just a guess, and may always be!



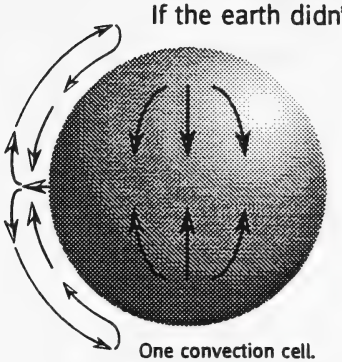
Dopplar radar

If a cloud shows both approaching and receding raindrops (and therefore winds), it has spiralling winds in it and may form a tornado.

Lastly, a word about **chaos theory**. Edward Lorence, a meteorologist, discovered that the weather was sufficiently complex that its behaviour couldn't be predicted beyond a certain time. Tiny changes in

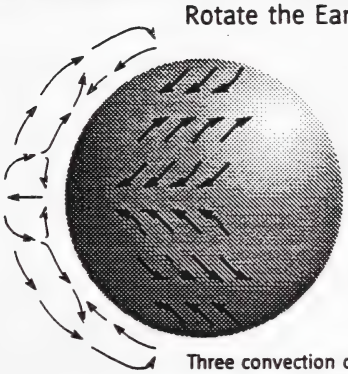
Global Climate

If the earth didn't rotate



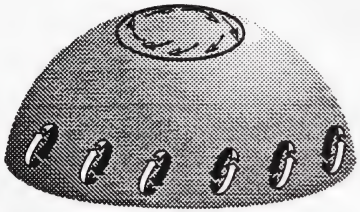
One convection cell.
Surface winds would blow from the poles to the equator. This doesn't happen.

Rotate the Earth

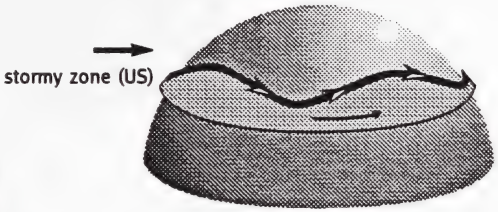


Three convection cells. Wind directions depend upon latitude. This is the model seen in most texts. It has been around for 60 years or so. It's not bad but.....

1. Polar Easterlies seep out from the poles.

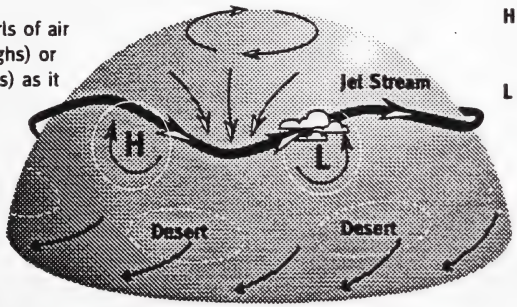


2. Trade Winds are part of a convection cell near the equator.



3. The Jet Streams zig-zag around the Earth's "stormy zone", transferring heat from the equatorial zones to the poles.

Jet stream causes swirls of air that are clockwise (highs) or counterclockwise (lows) as it rises and falls.



H – high pressure area
– clear, calm

L – low pressure area
– cloudy, windy, stormy

Doldrums – Band of Low Pressure

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Science, Technology & Society

TOXIC

WASTES

A Problem in Search of a Solution

ACCESS NETWORK

TOXIC WASTES

To the Teacher

This video program and guide are meant for use with students, to bring the topical issue of toxic waste into the classroom in a balanced way. One of the most important tasks of science teachers is to help students understand the science behind controversial issues in order to promote the idea that, as citizens, we all have a role to play in solving environmental problems—but first we must understand them.

The video provides an opportunity for discussion of the advantages and disadvantages to society of continuing to use and produce substances that can potentially cause harm. The information in this video should help students to understand the problem, while providing hope for a solution. It should help students make choices that will have a positive influence on the environment.

The program is suitable for use as an introduction to a unit in chemistry or as the culminating activity in a unit of integrated science, and has curricular fit with the STS connections in several of the Alberta Senior High Science programs of study.

After viewing this video, students should be able to:

- explain what toxic wastes are
- categorize toxins according to the damage they cause
- describe some of the effects caused by toxic wastes
- name some significant common toxic wastes and describe their sources
- describe some ways in which industry is minimizing the release of toxic wastes
- briefly explain the process by which wastewater is treated in a large city
- describe some ways in which individuals, in their everyday activities, may contribute to solving the toxic waste problem.

Overview of *Toxic Wastes*

Could toxic wastes eventually destroy our planet? In a light-hearted introduction to a serious topic, the monster "Toxilla" directs viewers' attention to the subject of toxic wastes. Alarm and panic are common responses to this potential threat to our environment; however, once we understand the problem and discover the ways it is being addressed, particularly how individuals can be part of the solution, toxic wastes are not so formidable.

Understanding the Problem

We sometimes refer to our planet as fragile when in reality it is practically indestructible, having withstood ice ages, bombardments of cosmic radiation, and collisions with comets and meteoroids. However, one aspect of the planet may well be too delicate to withstand toxic wastes—the ecosystem that sustains human life.

In the last 100 million years, numerous species have come and gone and the physical features of Earth have changed dramatically. Should we destroy the ecosystem that sustains us, the planet will survive and other creatures who thrive under the new set of conditions will rise up in our stead. It is the set of conditions favourable to human life that is most at risk of being altered by toxic wastes and other environmental hazards. Largely through scientific research, we are coming to understand threats to the environment and developing the knowledge and technologies to alleviate them. "Toxilla" cannot destroy us as long as we have the will to use our powers of learning and reasoning to find ways to reduce the threat of toxic wastes.

Understanding what makes a substance toxic can help lessen unreasonable fears of chemicals, preventing us from making hasty decisions. Toxic substances react with the chemistry of a living organism in such a way as to impair or threaten life. One way of categorizing toxins is according to the damage they cause.

Corrosive substances destroy living tissue by reacting with it. These include strong acids, bases and oxidizing agents; *e.g., sulphuric acid and ammonia (both used in fertilizer production), sodium hydroxide (in drain cleaner), chlorine gas (pulp bleaching agent), hydrogen peroxide (disinfectant), sodium hypochlorite (in household bleach).*

Metabolic toxins interfere with biochemical processes such as cellular respiration; *e.g., carbon monoxide (produced from the incomplete combustion of fuels, also present in cigarette smoke), hydrogen sulphide (naturally occurring in sour gas), cyanide (rodenticide), formaldehyde (tissue preservative), aniline (textile dye), sodium nitrate (meat preservative), ozone (in photochemical smog).*

Neurotoxins interfere with the functioning of the nervous system; *e.g., nicotine (in tobacco products), lead compounds (a byproduct of combustion), methyl mercury (present in waters near the effluent discharge from manufacturers of electrical equipment), organophosphates, carbamates and organochlorinates (all present in pesticides), methanol (a solvent in antifreeze, paint, ink).*

Mutagens are capable of affecting genes and chromosomes by altering the structure of the DNA and RNA, thereby inducing mutations in the genetic code. This results in changes to the genetic structure in future generations. *Examples of mutagens include radiation (from X-rays) and benzopyrene (in coal tar, cigarette smoke and charbroiled meat).*

Note: *Even though it is described as such in the video, sodium nitrate is not considered a mutagen in humans, but rather a metabolic poison. Sodium nitrate is added to cured meats for protection against botulism. Nitrate compounds are part of nature's cycle of decomposition of organic matter and are naturally present in many food crops and water sources. They are only a danger if ingested in relatively large amounts.*

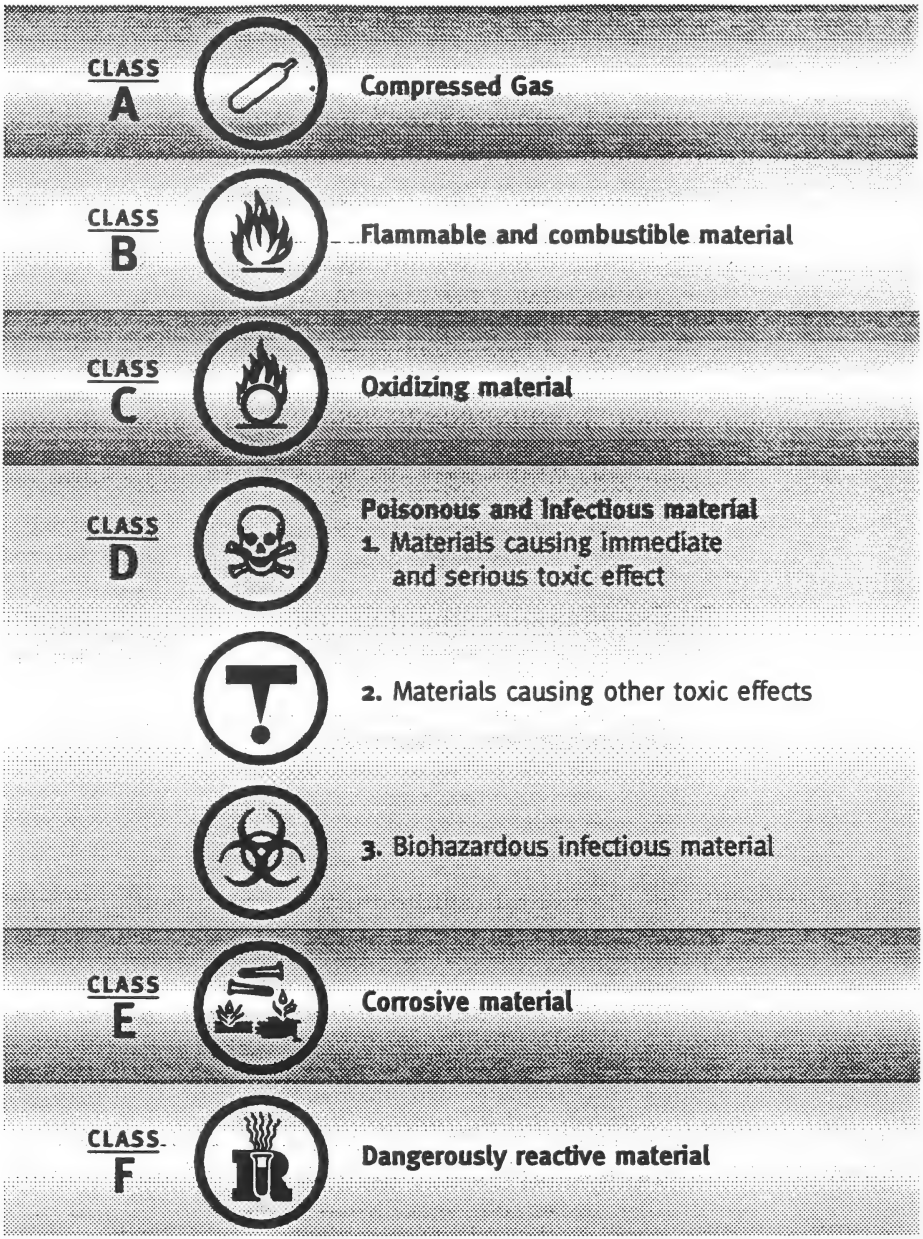
Teratogens act on the human embryo when it is in the uterus causing developmental abnormalities. The factor usually has to be present during the first three months of gestation when cell differentiation is most rapid. *Examples of teratogens include radiation (X-rays), ethanol (in alcoholic beverages), viruses (such as rubella).*

Carcinogens are substances that cause cancer, or uncontrolled cell division. *Suspected carcinogens include benzopyrene, benzene (a gasoline additive), certain dioxins (in chlorine bleached pulp), carbon tetrachloride (a solvent), formaldehyde (in pressed wood products), heavy metals such as beryllium, and cadmium, nitrosamines (may form in the gut when meat containing nitrates and nitrites are eaten), vinyl chloride (used to make PVC plastics).*

A toxic substance becomes hazardous when it is placed in the environment where it can come into contact with living things and potentially cause harm. The Workplace Hazardous Materials Information System (WHMIS) describes another way of categorising substances that could become toxic wastes:

- **Corrosive substances** eat and wear away at materials; *e.g., battery acid, drain cleaner.*
- **Toxic substances** are poisonous or lethal in small quantities. Some of these materials cause immediate and serious toxic effects; *e.g., rat poison, antifreeze, insecticide,* while others are slower-acting and cause other toxic effects; *e.g., mercury, lead, cadmium.*
- **Flammable and combustible materials** can ignite when in contact with a spark or flame; *e.g., lighter fluid, gasoline.*
- **Biohazardous materials** contain infectious pathogens; *e.g., viruses and bacteria.*
- **Dangerously reactive materials** can explode or produce deadly vapours; *e.g., aerosol cans containing paints or solvents.*
- **Oxidizing materials** are unstable chemicals that undergo reactions very easily, possibly releasing toxic gases, or they support combustion by providing a source of oxygen; *e.g., bleaching agents such as chlorine or hydrogen peroxide and potassium permanganate, which may be used as a water disinfectant in rural areas.*

WHMIS symbols



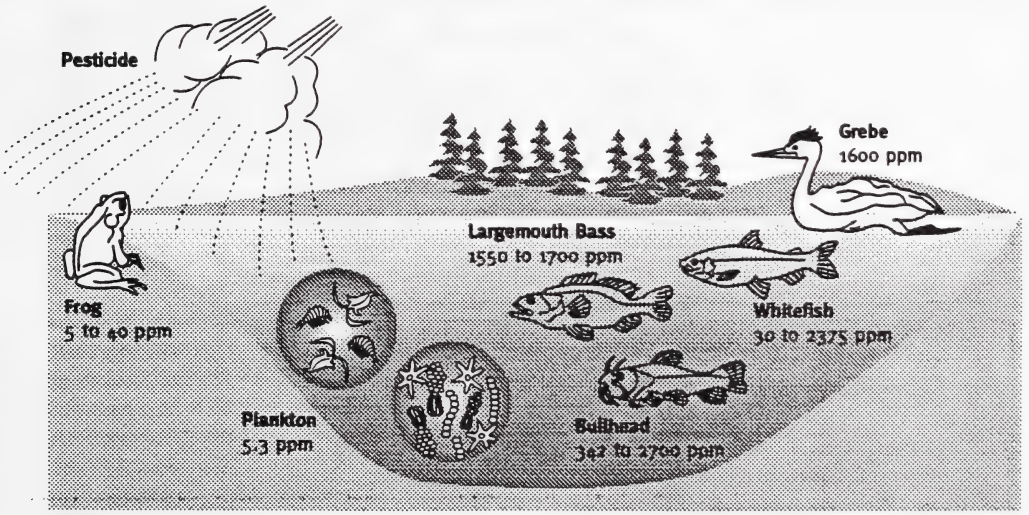
Wastes are substances for which we have no further use. Toxic wastes, therefore, are hazardous substances we wish to discard. Worldwide, humans now generate more than 6 billion tonnes of hazardous wastes and wastewater, in Canada almost 6 million tonnes.

Hazardous wastes are produced by a variety of human activities such as mining, smelting, oil production, refining and distribution, agriculture and energy production, and the manufacture and use of products including pesticides and herbicides, chemical preservatives and solvents, paints, dyes, explosives, rubber and plastic, batteries, pulp and paper, pharmaceuticals, fabric and leather. When we bring these products into our homes, then use or discard them, we add to the toxic waste problem.

Accidental spills of hazardous substances can occur at manufacturing sites, during their transport to another site, or as they are being used at home or on the farm. Toxic wastes may be in the form of solids, liquids or gases and may enter the air, water or soil, with air emissions, discharge effluents or discarded solids (solid waste).

As toxic substances move in the environment they create risks for humans and other species, either by the immediate effects of exposure or by gradual accumulation of smaller amounts. Toxic substances can also become bioconcentrated in the food chain, accumulating to the point of toxicity in third-order consumers, including humans.

The Concentration of a Pesticide in a Food Chain



LD 50, the dose that is lethal for 50% of a specified population, is often used to describe the toxicity of a chemical. It can vary immensely from species to species and also with age of the individuals; for example, older people and children may be more susceptible than others. Most LD 50 values are determined with experimental animals and extrapolated to humans. Therefore, the careful reasoning and judgment of expert scientists must translate the values into human terms.

Every chemical has some set of exposure conditions under which it is toxic and a set under which it is not toxic. Even table salt is toxic to humans if enough is ingested. We must be concerned not only with what a toxic waste does, but also in what concentrations it is harmful.

In the past the planet was believed to be large enough to dilute and render harmless whatever we put into it. Then it was believed that we had fouled the planet with toxic wastes almost to the point of destroying it. We now know that certain hazardous substances can be tolerated in relatively large amounts, but for others even the smallest amount has potential harmful effects. Many chemicals can be toxic under some set of conditions; however, we usually apply the word toxin or poison to a relatively small number of substances that cause harm or are lethal in very small quantities. Even in a diluted form, these should not be released into the environment.

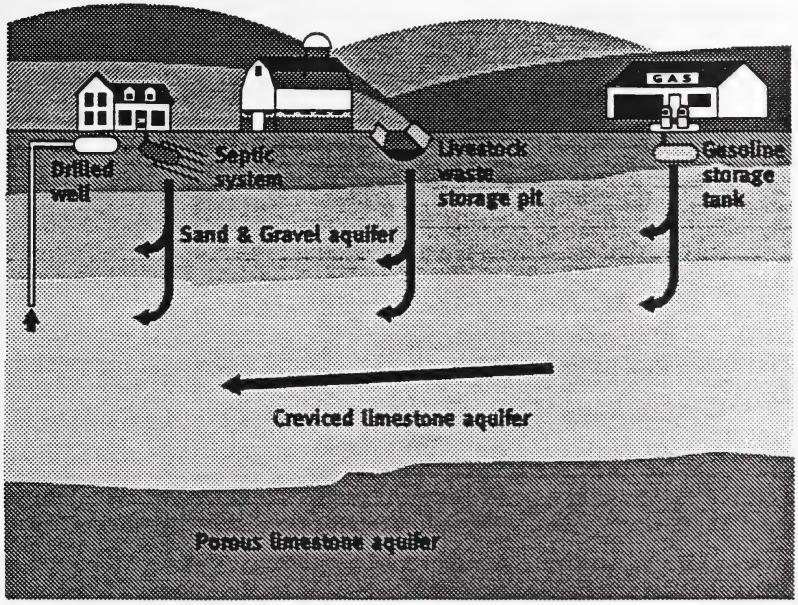
Solutions to the Problem

Paranoia about toxic waste can prevent us from thinking rationally about the problem, while clear-minded reasoning, with the help of scientific facts, can show us possible pathways out of the toxic waste dilemma. The first steps are to define the problem we are dealing with, then gather relevant information (this is where the scientists are heavily involved) about the problem and then develop solutions. Often technologists are involved in the solutions, but we all have a role.

Toxic substances that enter the air can affect the most living things because they can be widely distributed in a very short time, and recapturing them is nearly impossible. Humans, for example, inhale large volumes of air, about 20,000 litres per day, and with each breath we take in any toxins that may have contaminated the air.

Discharge liquids, even when contained in settling ponds or containers, often eventually make their way into waterways and contaminate nearby aquatic ecosystems and underground groundwater. It is very difficult to remove toxins from water systems, particularly from groundwater.

Solid wastes are probably easiest to contain, but storing them for long periods of time in containers or incinerating them may be a financial burden for society. Not too many years ago most toxic wastes were disposed of with other wastes in landfills or waterways—no special treatment was given them. Now we have in place strict regulations against dumping hazardous wastes and have developed elaborate methods to deal with them. Following are various ways society is addressing the toxic waste issue.



Minimization

The best solution is not to produce the toxins in the first place, but it seems to be difficult for society to give up the products that require toxins in their production or the technologies that produce toxic substances. The next best control of toxic wastes is to produce as little as possible of the offending substance and not to release any into the environment.

In the petroleum industry the emission of volatile hydrocarbons has been reduced by covering tanks, maintaining storage tanks at low temperatures and using 'closed in' connectors. The system used by the Dow Chemical Company to contain methanol as it is being transferred between containers is described in the video. Specialized scrubbers are in place at many industrial sites to remove toxins from smoke-stack emissions, and other industries have settling ponds to collect hazardous substances and treat them before releasing waste waters.

Alternatives

Products can be reformulated to require less or no toxic substances. Current examples include the phasing out of solvent-based paints and inks and using less-toxic substitutes in wood preservatives; as well, lead compounds are no longer added to gasoline. There are many toxic household substances for which substitutes can be used.

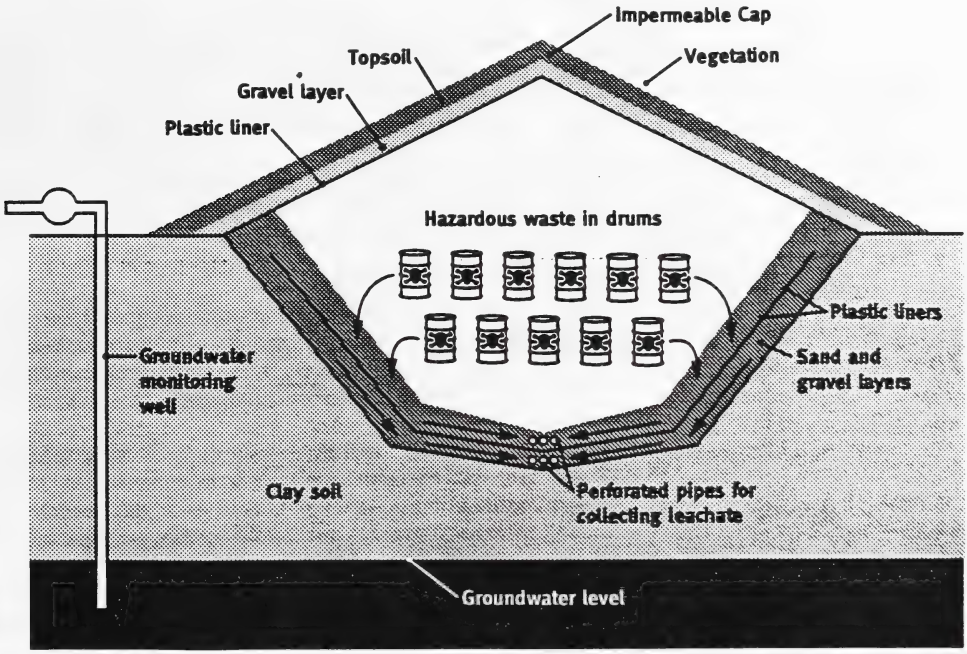
Instead of:	Use:
bleach	hydrogen peroxide, vinegar and borax
drain cleaner	a plunger, baking soda and vinegar
moth repellent	cedar chips, dried lavender petals
portable batteries	rechargeable or solar batteries
carpet cleaner	club soda, salt, cornstarch
ant killer	borax, diatomaceous earth
slug killer	stale beer set out in containers
aphid spray	soap solution, blended garlic and onion tops
oil-base paint	water based paints made with natural ingredients, whitewash made with limestone

Every time a person lights up a cigarette they are adding toxic carbon monoxide, benzopyrenes and a host of other harmful substances to the nearby environment. The alternative is to give up smoking.

Containment

Permanent storage in secure sites may be the only way to contain certain toxic compounds. In deep well disposal, liquid effluents are pumped into deep underground caverns within impermeable rock formations.

Secure landfill sites, such as is shown on page 9, consist of plastic-lined excavations in clay soil with sand and gravel on the bottom to collect leachate if it should escape from the hazardous waste contained in drums. The site must not reach the level of the groundwater and the groundwater must be monitored for possible contamination. There must also be an impermeable cap on the site to prevent natural precipitation and runoff from entering it.



Treatment

Sometimes it is permissible to release a substance if it is sufficiently diluted, but the better route is always to detoxify it. Chemical treatments involve precipitation of dissolved toxic substances from the effluent and removal as a solid. Since some solids thus formed are soluble in acidic solutions a further step may be taken in which the substance is fixed in a material such as portland cement to prevent any leaching into the environment.

Breaking down substances into their harmless components is a method that can be used only with a small proportion of toxic wastes. When natural or genetically altered microbes are used to break down specific toxins, the process is called bioremediation. One method involves separating out natural bacteria that feed on a particular toxin in a polluted environment and reproducing them under ideal conditions until a sufficient number are present to detoxify a site. A bioreactor is illustrated on page 11.

In incineration, the offending substance is burned at a sufficiently high temperature to break it down to simple compounds such as carbon dioxide and water or the component elements. This is the final step used at the Swan Hills Waste Treatment Plant, when no other method will detoxify a compound.

On the following page, the steps by which special waste is transported to and processed by the Swan Hills Waste Treatment Plant are outlined.

Swan Hills Waste Treatment Plant Process

START

1 **Waste Enters the System** Many businesses and households generate small amounts of special waste. Households can dispose of waste during a community toxic roundup, while businesses dispose of small quantities of waste at Transfer Stations. Businesses that consistently generate waste must identify the chemical and physical properties.

2 **Waste Collection** Transfer Stations are located across Alberta. Waste generators transport their special waste to these stations, although larger quantities are transported by the system directly to the Treatment Centre.

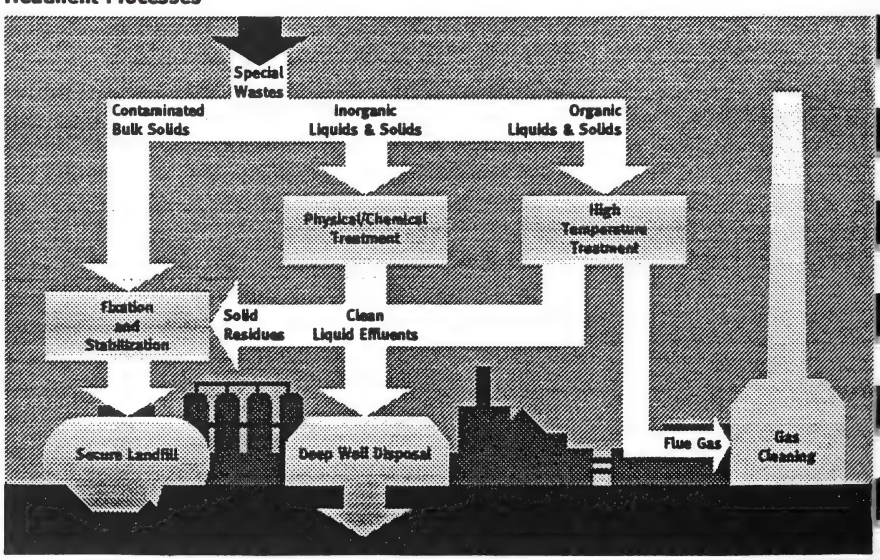
3 **Waste Documentation** A waste manifest accompanies each shipment from the point of generation through disposal. The multi-part form describes the generator, carrier, receiver, waste type, form, volume and shipping information. Government agencies receive copies to track shipments to ensure safe transport.

4 **Transportation Network** Chem-Security (Alberta) Ltd. manages the transportation system and collects waste from Transfer Stations or a generator's site. Two large steel containers are located on the trailer of each truck, and drums of waste are lifted into these safety containers for transport. Specially designed vehicles haul bulk liquids and solids.

5 **Road Safety** Trucks hauling special waste have placards that identify the type of waste being hauled. All trucks are checked thoroughly before departure and are inspected en route.

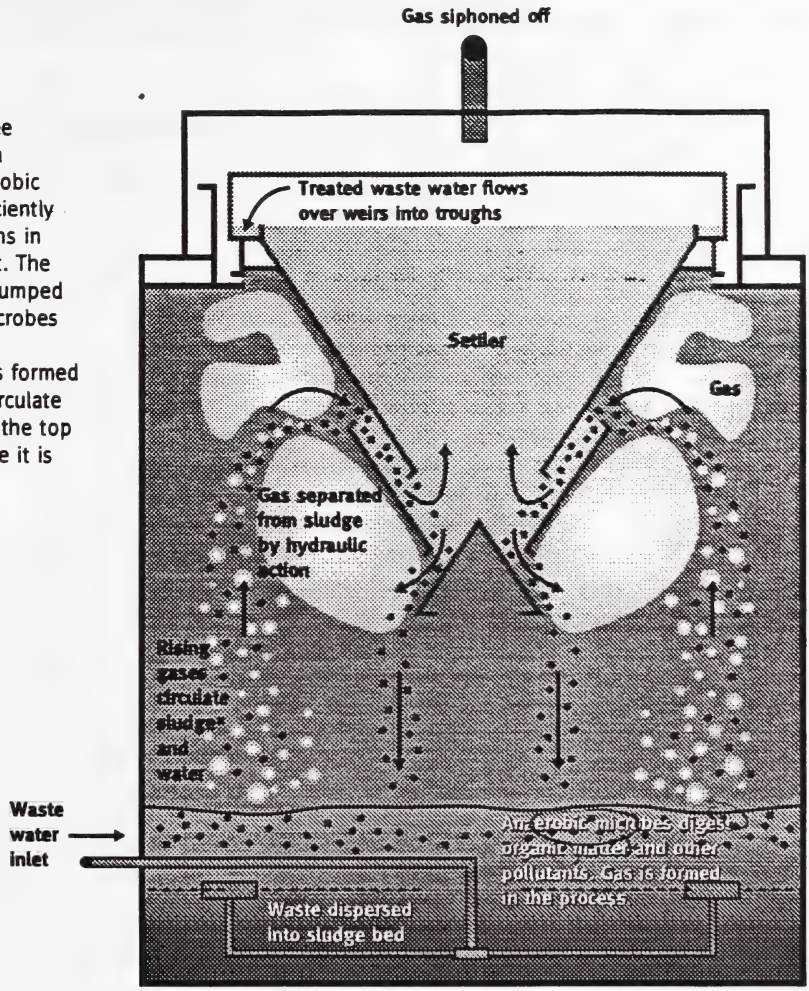
6 **Verification and Analysis** All wastes received at the Treatment Centre are assigned an identification number as a record of treatment and disposal. The Centre's laboratory confirms that the waste matches the description on the generator's waste profile sheet, and waste previously approved for treatment and disposal undergoes a 'fingerprinting' procedure. The lab then verifies that treatment and destruction processes are appropriate and sufficient.

7 **Treatment Processes**



Inside a Bioreactor

In the oxygen-free environment of a bioreactor, anaerobic bacteria can efficiently break down toxins in pulp mill effluent. The waste water is pumped into a bed of microbes which digest the pollutants. Gases formed in the process circulate cleaner water to the top of the tank where it is drawn off.


Gas siphoned off
Treated waste water flows over weirs into troughs
Settler
Gas
Gas separated from sludge by hydraulic action
Rising gases circulate sludge and water
Waste water inlet
Anaerobic microbes digest organic matter and other pollutants. Gas is formed in the process.
Waste dispersed into sludge bed

Clean-up of spills and contaminated sites

Clean-up of contaminated sites can involve hauling away soil and incinerating it or treating water to remove the toxin. Contaminated soil usually has to be removed from a site and stored in impermeable containers or incinerated. Firefighters and other specially trained individuals are called to spill sites and have the equipment and chemicals to mop up the residues. For example, an acid spill will usually be neutralized with an appropriate base before it is diluted with a large amount of water. Then it can usually be safely flushed into a drain.

A mercury spill at a school site would be treated differently. Because of the toxicity of mercury vapour, every last trace must be removed with a vacuum device or by treatment with isopropanol and sulphur to convert the mercury to mercury (II) sulfite. A spill of ammonium nitrate fertilizer would be treated with sodium hydrogen sulfite to reduce the potential of explosion.

Activities for Students

1. Use a reference source such as a dictionary of chemicals or a medical book to find the sources and toxic effects of each of the following substances:

   dioxin, methanol, formaldehyde, arsenic, dieldrin, chromium, lead, pentachlorophenol (wood preservative), benzene, selenium, cadmium, xylene, toluene, acetone, chloroform.

2. Complete this chart by placing examples of the toxic wastes produced in each block; then review your chart to suggest ways of reducing the release of each toxic waste.

Category of Emission

Source	air emissions	liquid effluents	solid wastes
industrial			
commercial			
agricultural			
domestic			

3. Prepare an inventory of the substances in your home and school that could potentially become toxic wastes. How are they labelled? How are they handled? What plan is in place to dispose of them when they are no longer needed? List some alternatives that might be used instead of these particular substances.

4. Look in a book on human biology to find out how carbon monoxide acts as a metabolic poison and how organophosphate insecticides act as neurotoxins.

5. Use a reference source to find the relationship between chelation therapy and heavy metal poisoning.

6. Take a visitors tour of the Swan Hills Waste Treatment Plant. Go prepared with some questions to ask the tour guide.

7. You heard in the video how a chemical company 'recaptures' methanol vapour that escapes from containers when it is being transferred. Residual vapour is then scrubbed with water.

   a. Explain, on the basis of hydrogen bonding, how water can be used to 'scrub' methanol out of air. Describe an analogous situation where methanol is used to remove water from a fuel.

   b. The video states that a similar problem exists at service stations—when gasoline is being pumped into cars, some of it vaporises and escapes into the air. Suggest a design for a technological solution for this problem at gas stations. Draw a sketch of your design.

8. Copper ions are acceptable in water effluent at a concentration of 5.0 ppm. A technician tests for copper ions in a water sample and finds the concentration to be 0.0012 mol/L. Perform the calculations to determine if this is within acceptable limits.

9. Copper in its ionic form is considered to be a toxic substance in concentrations above 5.0 ppm. There are various ways of removing copper

ions from water. One is to use another metal to displace it from solution.

a. Refer to an activity series to find a possible metal that could be used to displace copper from solution and design a procedure for testing it. Another method involves precipitating the copper ions in an insoluble compound.

b. Use a table of solubility to find an appropriate compound for precipitating copper ions from aqueous solution. Design and test a procedure using this principle. **Note:** *Check with your teacher before proceeding and don't discharge any solutions containing copper ions into the environment.*

10. Imagine you are a safety officer and that a hazardous substance such as mercury has spilled in the lab. Do some research to find out the procedures you would follow to clean it up and keep those nearby safe from harm.

11. In various parts of the world environmental accidents have occurred in which toxic substances have been released with disastrous results. Do some research into the following case studies, explaining the causes of the release, the toxin involved and what it was being used for, the health effects on nearby residents, and how such an incident might have been prevented.

    a. Love Canal near Niagara Falls, N.Y.

    b. Minimata, Japan

    c. Bhopal, India

    d. Chernobyl, Ukraine

12. Alberta recently passed a law requiring owners of contaminated land to clean up the mess before the land can be sold. A man in Ryley, Alberta, is contesting the law because he says the previous owners contaminated it without his knowledge. Who do you think should be responsible for cleaning up contaminated sites?

13. The Swan Hills Waste Treatment Plant is the only toxic waste centre in Western Canada and the only one in Canada able to destroy PCBs, the suspected toxic/carcinogenic waste from electrical transformers. There is concern, however, that transporting toxic wastes over great distances to Swan Hills is a danger to communities along the route, because of accidents. On the other hand, accidents, fires or vandalism can cause release at storage sites. Discuss this issue, outlining the advantages and disadvantages of each alternative.

14. We continue to use many toxic substances because we perceive them as providing some benefit to us. Prepare a chart outlining the risks and benefits of a particular toxic substance that is used frequently. Some examples you might consider are X-rays, lead-acid car batteries, pressed wood products, insecticides and herbicides.

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The Lowdown on ADDITIVES

The Lowdown on ADDITIVES

All things are poisons, for there is nothing without poisonous qualities. It is only the dose that makes a thing a poison."
... Swiss physician and alchemist
Philippus Aureolus Paracelsus (1493-1541)

To The Teacher

One of the most important tasks of science teachers is to help students understand the scientific facts behind controversial issues. This program presents an objective look at food processing and food additives. Students will see why additives are an integral part of the food industry, and explore different types of additives and their uses.

Even "natural" foods are made up of a complex mixture of chemicals, which often includes toxins. Students will see that most of our food is perfectly safe to eat, as long as it is part of a balanced diet.

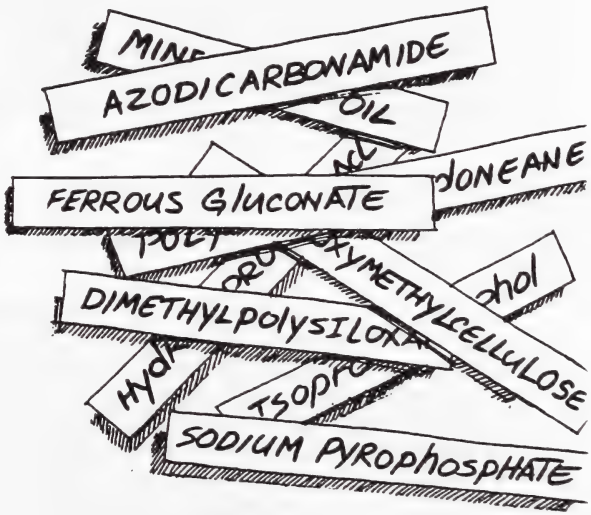
This video program is intended for use with integrated science, biology, chemistry, and physics courses at the senior high school level. Although it is geared to a high school audience, the program is also valuable to junior high students who are studying micro-organisms and food.

An interesting issue raised in this video is that of public opinion versus scientific knowledge. Why are there so many misconceptions about food additives? Is this a failure of the media, or are scientists responsible for providing information to the public?

Overview of *The Lowdown on Additives*

As the program opens, two young people in a grocery store are choosing from a vast display of foods, and discussing the additives on food labels. Related questions about the food additive issue are answered in the video. We learn that additives are not new, but have been used for thousands of years. We find out what food additives are, and why they are used in food processing. We examine the safety of food additives, and see how food testing is carried out. In the course of discovery we gain insights from food scientists and government food inspectors.

So what is the truth about food additives? As with many other issues, the more we learn, the less likely we are to see things in absolutes. Looking at food safety from a scientific perspective, food poisoning becomes a far greater health concern than food additives.



Information on Additives

Are Additives New?

Evidence suggests that food preparation and additives have gone hand in hand since the earliest civilizations. More than 3000 years ago, chefs were adding saffron, tumeric and paprika to enhance the colour of foods. Smoking and salting were ancient methods of preserving meat and fish. For the past several hundred years, people have been using saltpetre (potassium nitrate) as a curing agent.

Additives seem new because they are so prominent in today's food supply. One contributing factor has been the migration of people to cities. Over the past 50 years, the majority of the world population has become farther removed from its sources of food than ever before in history. Foods are shipped long distances across continents and oceans, and must be kept fresh.

Growth in populations has also prompted a more liberal use of food additives. We need enormous quantities of food to keep our cities well-stocked. Extending the shelf life of foods is crucial to maintaining a safe, adequate, and affordable food supply.

Advances in technology, the demand for convenience foods, and the more recent demand for low sugar and low fat foods have prompted a greater use of food additives. For example, low fat ice cream requires additives in order to create a pleasing texture while providing a healthier choice for discriminating consumers.

What Are Additives?

A food additive is a chemical that is added to food for a particular reason. The reason may be to preserve the food, or to enhance its texture or appearance. Food ingredients such as salt, sugar, starch, flavouring preparations, seasonings and spices are not considered to be additives.

Why Use Additives?

The main reason for using additives is to check the growth of micro-organisms so that foods will last longer. While bread can be made without additives to inhibit the growth of mould, it costs about five cents more per loaf. This is because bread without additives has a shorter shelf life, and must be transported quickly to markets.

Some additives are used to improve the appearance of the food product. Ascorbic acid, the chemical name for Vitamin C, keeps canned food looking fresh. Without this additive, many foods would turn dark in the tin.

Sometimes the nutrients in food will break down unless a chemical is added. Butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT) in margarine are antioxidants, and protect the food's Vitamin A supply.

The following table lists some (not all) of the categories of additives and the reasons for adding these substances to foods. A few examples are listed from each category, but there are many more examples than the ones listed here.

Anticaking Agents
Prevent powders, such as salt and flour, from clumping. *Example:* calcium silicate, magnesium oxide, sodium aluminum silicate

Antifoaming Agents
Prevent foaming during the processing of foods such as jam. *Example:* monoglycerides, dimethylpolysiloxane

Antioxidants
Slow the process of oxidation, which makes fats turn rancid and frozen fruits turn brown. *Example:* citric acid, ascorbic acid, acetic acid, BHA (butylated hydroxy-anisole) and BHT (butylated hydroxytoluene), lecithin

Bleaching Agents
Produce a consistent colour in foods such as flour. *Example:* ascorbic acid, chlorine dioxide

Colouring Agents
Improve appearance of food. *Example:* caramel, carbon black, iron oxide, paprika, riboflavin (vitamin B)

pH-adjusting Agents
Increase or decrease acidity in food. *Example:* acetic acid, ammonium bicarbonate, calcium acetate, magnesium hydroxide

Preservatives
Prevent or delay food spoilage caused by microbial growth, yeasts or moulds. *Example:* sodium sulphite, sodium benzoate, potassium nitrite, potassium nitrate (saltpetre), sodium nitrite, woodsmoke, tartaric acid

Sequestering Agents
Combine with metallic elements in food, so that metals do not enter into reactions that could change the colour or taste of the food. *Example:* calcium disodium ethylene diaminetetraacetate (calcium disodium EDTA), calcium phytate, glycine

Sweeteners
Sweeten foods with a minimum of added calories. *Example:* aspartame, mannitol, sorbitol, xylitol

Texture-modifying Agents
Produce a desirable consistency in food. This group includes emulsifying, stabilizing, thickening and gelling agents.

- Emulsifiers keep oil droplets suspended in another liquid (mayonnaise). Example: mono and diglycerides, lecithin
- Stabilizers keep suspended food particles from settling to the bottom (chocolate milk). Example: guar gum, locust bean gum, carrageenan
- Thickeners adjust consistency of processed products (ice cream). Example: sodium carboxymethyl cellulose
- Gels promote formation of gels (gelatin desserts, jams). Example: gelatin, pectin

Vitamin Supplements
Prevent diseases caused by vitamin deficiencies. *Example:* vitamin D added to milk

Other categories of additives include:

Carriers or Extraction Solvents
Firming Agents
Food Enzymes
Glazing and Polishing Agents
Humectants
Pressure-dispensing Agents
Release Agents
Starch-modifying Agents
Whipping Agents
Yeast Foods
Miscellaneous Agents used in carbonating, filtering, deodorizing, plasticizing (chewing gum), foaming and tableting processes

Artificial Flavours

Flavouring Agents are listed on food labels as ingredients, but are not considered to be food additives. Amyl butyrate can be used to create the flavours of apricot, peach, plum, pineapple or pear. Cinnamaldehyde gives a cinnamon flavour, ethyl vanillin a vanilla flavour, and methyl salicylate a wintergreen flavour. Artificial flavours are commonly used in powdered drinks and candies.

Why Are Additives Distrusted?

Most people think natural foods are healthier than foods containing additives. The food industry is aware of this, and now markets products by advertising "No Preservatives" or "No Additives." Researchers in the food industry are trying to "clear up the label", not for any health reasons, but because of the public's concern over additives.

People think of chemicals as artificial and distrust additives because they are made of chemicals. We sometimes forget that all foods are made up of chemicals. Whether those chemicals are natural or artificial does not matter to the body. Citric acid from lemon juice is processed by the body in the same manner as citric acid from a lab.

The media have contributed greatly to people's mistrust of food additives. Sensational press about the dangers associated with different food additives leads people to complain that every food seems to be harmful.

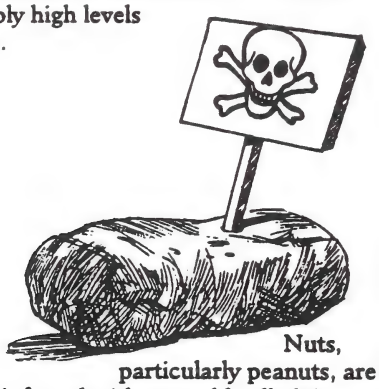
Much of the public concern about diet should be directed at processed foods themselves rather than additives. Many processed foods contain unnecessarily high levels of sugar, salt, and fats that, in excess, are harmful to health. However, sugar, salt and fats are classified as *food*, not additives. Manufacturers are beginning to respond to consumer concerns by restricting sugar, salt and fat levels in more of their processed food products.

Even so-called "junk foods" like pop and french fries are not unhealthy unless they are eaten in excess. The argument can be made that many North Americans do include excessive amounts of sugar and fat in their diets. This, combined with a

sedentary lifestyle, may be contributing to a high percentage of overweight people. A balanced diet contains plenty of fresh fruits and vegetables and a variety of other foods.

Is "Natural" Always Good?

Because we equate "natural" with "good", or "wholesome", we tend to overlook the fact that some natural foods produce toxic chemicals. The potato, a staple in many diets, contains over 150 different chemicals. Some of these are toxic, including solanine, alkaloids, oxalic acid, arsenic, tannins and nitrate. Since the concentrations of harmful chemicals are small, potatoes are good for you–with one exception. If the potato has a greenish-tinged skin, or is sprouting, the peel is harmful and should be discarded. It contains unacceptably high levels of solanine.



Nuts, particularly peanuts, are commonly infected with a mould called Aspergillus flavus, which produces the carcinogen, Aflatoxin B. Roasting destroys up to half the aflatoxin, and mechanical or manual sorting reduces the levels even further. Products which show more than 15 parts per billion of aflatoxin cannot be sold in Canada. When it comes to peanut butter, processing actually reduces a naturally occurring toxin.

Natural Toxins

Earth's plant life contains many substances that have been developed as medicines. It also contains poisons. Alkaloids, found in potatoes and some other vegetables, are used in the production of morphine, quinine and strychnine. Strychnine has proven for centuries to be an effective natural rat poison. Heroin and opium are derived from the poppy plant, marijuana from the hemp plant, and cocaine from the leaves of the coca plant. High levels of cyanide are found in the shoots, twigs and seeds of apples, cherries, peaches, plums and apricots. Mushrooms come in all varieties–from edible to hallucinogenic, to highly toxic. The stimulant caffeine is found in natural products such as coffee, tea and cocoa. Ten grams of caffeine can kill an adult.

More poisons enter our bodies each day as *natural chemicals* in the *natural foods* we eat than from all other sources combined.

Many substances naturally present in food would not be approved for use today if they had been manufactured in a laboratory and submitted to Canada's Health Protection Branch. Vitamin A is a good example. Eating ten times the recommended intake of Vitamin A could be toxic. Additives, on the other hand, must have a safety factor of one hundredfold. They must contain 100 times less quantity of additive than the "no-effect" level for humans. (See p. 5 for explanation of the "no effect level".)

Some Toxins or Carcinogens Found Naturally in Food

Oxalic acid — *Found in rhubarb and spinach. Can lead to kidney damage.*

Tannic acid — *Found in coffee, black tea and cocoa. Can cause cancer of the mouth and throat.*

Dimethylnitrosamine — *Found in cooked bacon. Can cause cancer.*

Glycyrrhizic acid — *Found in licorice. Can lead to hypertension and cardiovascular damage.*

Hydrazines — *Found in raw mushrooms. Can cause cancer.*

Myristicin — *Found in black pepper, carrots, celery, dill, mace, nutmeg and parsley. Can cause hallucinations and liver damage.*

In every case, it's the dose that makes the poison. Eating 100 grams of licorice per day for several consecutive days could cause health problems. Drinking 70 cups of coffee in one day would be a lethal dose of caffeine. Even water is lethal if taken in excessive amounts. If we eat a variety of foods in moderation, most natural toxins will not cause health problems.

Nature's Chemicals

While we think of food additives as being synthetic chemicals, in many cases they are derived from natural products. Carrageenan comes from seaweed extract. It improves the texture of ice cream, and actually adds healthful fibre to the product. Lecithin is a product of soybeans. It is used in whole milk powder to help the milk dissolve in water. Locust bean gum comes from seeds, and carboxymethyl cellulose is a product of wood pulp.

Some chemical and common names of foods and food additives are as follows:

Chemical Name	**Common Name**
citric acid	lemon juice
sodium chloride	salt
acetic acid	vinegar
sucrose	table sugar
glucose	corn syrup
fructose	fruit sugar
ascorbic acid	vitamin C
sodium bicarbonate	baking soda
papain	papaya extract (meat tenderizer)
cinnamaldehyde	cinnamon
monosodium glutamate	MSG

Are Additives Safe?

Although we don't always make healthy dietary choices, the food we eat is almost always safe. Canada has one of the world's safest food supplies. All ingredients used in processed foods must be listed on the label, in order of quantity, from greatest to smallest. Additives are not permitted in some products such as fresh eggs, milk* and meat.

Canada's Health Protection Branch has a list of approved food additives. It is a relatively short list, and only one or two new substances are added in a year. New additives must pass stringent safety tests before being included on the approved list.

The amount of a food additive is usually measured in parts per million (ppm). Scientists determine the allowable amount by first establishing the "*no-effect level*". This is the amount of additive which can be given *without* causing any reaction in testanimals.

Once the "no effect level" is established, then the "Acceptable Daily Intake" (A.D.I.) of the additive is worked out. Usually this involves dividing the "no-effect level" by a safety factor of 100.

For example, if the "no-effect level" of a substance is found to be 1000 mg. per kilogram of body weight, the Acceptable Daily Intake is calculated at 10 mg. per kilogram of body weight *per day over a lifetime.*

While most additives are completely harmless, nitrites *have* been linked with cancer. They can react in the stomach to produce the carcinogen **nitrosamines.** Nitrates and nitrites are commonly added to cured meats. They enhance the flavour and colour. But most importantly, they prevent the growth of Clostridium botulinum spores. These bacteria produce an extremely dangerous and potentially fatal type of food poisoning called botulism. The risk of developing cancer from eating nitrites is minimal compared to the risk of botulism.

Eliminating all cured meats from one's diet would decrease the total intake of nitrites by only about 22 per cent. Many vegetables, including spinach and carrots, contain nitrates. When nitrates combine with the bacteria in saliva, they produce nitrites. Therefore, a good portion of our nitrite consumption comes from "natural" foods. Vitamin

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** With the exception of Vitamin D, which is added to milk to prevent deficiencies. Vitamin D helps the body absorb calcium. We get vitamin D from sunlight, but in northern climates, children may have little exposure to sunlight during winter months. Vitamin D added to milk prevents rickets, and other skeletal malformations.*

C eaten with nitrites has been found to decrease the production of nitrosamines.

A small percentage of the population is allergic to certain additives such as sulphites. These individuals must take special precautions, as do people with food allergies.

No Effect Level **÷ 100 =**	Acceptable Daily Intake Per Day (***For a Lifetime***)

The Real Danger

The greatest danger associated with eating food in Canada comes not from additives, but from microbial food poisoning. Symptoms of nausea, vomiting, diarrhea and stomach cramps are often mistaken for viral infections. For this reason, it is hard to pinpoint the number of cases that occur annually in Canada, but it is well over 100,000 and may be as high as half a million.

In the vast majority of cases, microbial food poisoning is caused by improper handling or storage of food. It happens in homes, restaurants and institutions. The main microbial culprits are Salmonella, Staphylococcus aureus, Campylobacter, and Verotoxigenic E. coli (VTEC). Bacteria can multiply rapidly in non-acid or low-acid foods such as eggs, meat or milk. The Campylobacter bacteria is found in unpasteurized milk.

Botulism is the least common but most dangerous form of food poisoning. The botulinum micro-organism is the most deadly poison known on earth. Five grams of the toxin (one teaspoon) would be enough to kill over one billion people. Tetanus and diphtheria toxins rank as the world's second and third most deadly poisons. One form of dioxin, which does not occur in nature but must be chemically produced, comes next, as the fourth most deadly toxin.

The majority of cases of botulism are a result of improper methods used in home canning of low acid vegetables and meat. Clostridium botulinum spores can be destroyed by heating the contents of a jar or can to 260 degrees Fahrenheit or 127 degrees Celsius. These temperatures can only be reached with a pressure canner.

Botulinum **is the "World's most deadly poison. 100% natural."**

Potential Hazards In Food

Scientists	**Consumers**
Highest	*Lowest*
Microbiological	
Animal Pharmaceuticals	
Environmental Pollution	
Pesticides	
Food Additives	
Lowest	*Highest*

Popular perception of what constitutes a danger in food is the opposite of scientific opinion

Monitoring Food Safety

Health Canada's Food Inspectors monitor food processing in Canada. They check a product's food ingredients and additives, and also ensure that sanitary conditions are maintained. Food inspectors are alert for the danger of cross contamination of ingredients. Because some people have severe food allergies, it is very important that ingredients from one type of food do not accidently spill into another type of food.

Food inspectors take samples of food for laboratory testing. Food is analyzed for its nutritional value,

and for additives and contaminants. It is also checked for extraneous material or filth, such as fragments of metal or glass, rodent hair, and insect parts.

Of Canadian foods tested, 99.76% are found to be in compliance with government guidelines.

Inspectors also check shipments of processed foods from other countries to make sure that the product is acceptable for sale within Canada.

Various methods are used to test foods. A simple chromatography test will identify the colourings found in food samples. This test has been used for over twenty years because it is fast and economical. Most testing for other ingredients is much more complex, involving computers, high technology instruments such as lasers, and a series of chemical processes to complete the analysis.

Sulphites

Canada's Food Inspectors test extensively for the presence of sulphites in foods. Sulphites can produce what is known as an "exquisite allergy" in affected individuals—a very small amount of this additive can quickly lead to an allergic reaction so severe that it may cause death.

Sulphites are preserving agents, and are permitted only in certain foods. They are always listed on the label of packaged foods, but may also be present in restaurant foods, and in bulk foods which are sold in supermarkets. Sulphites are now banned from restaurant salad bars, and are not permitted on fresh fruit, with the exception of grapes which are very prone to mould.

People who are allergic to sulphites must be extremely careful about reading food labels, and checking with the chef before they eat in restaurants. They should also avoid alcoholic beverages unless they are sure of the ingredients, because the beverages may contain sulphites.

Names of Sulphiting Agents

potassium bisulphite
potassium metabisulphite
sodium bisulphite
sodium metabisulphite
sodium sulphite
sodium dithionite
sulphurous acid

Sulphiting agents are commonly found in jams, relishes, tomato paste, catsup and puree, candies, fruit juices, frozen mushrooms, beverages. They must be listed on labels, with the exception of alcoholic beverages. (Steps are now being taken to legislate listing ingredients on alcoholic beverages.)

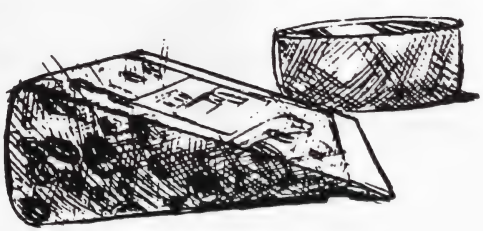
Unintentional Additives

Some additives end up in food by accident. These include mycotoxins such as Aflatoxin B, which result from naturally occurring moulds and fungi. Other unintentional additives may include agricultural pesticides and fungicides, residues of drugs commonly given to livestock, contaminants from food packaging, and fragments of extraneous matter, or filth, which may get into the food during shipping, storing, or processing.

Although these sound ominous, none is considered to be a significant health concern at this time. Consumers can reduce chemical residues by washing fruits and vegetables, peeling root vegetables, and discarding the outer leaves of leafy vegetables. Synthetic pesticide residues we may be ingesting from fresh fruits and vegetables compose only a tiny proportion (about one ten thousandth) of the natural pesticides and poisons contained in foods.

A simple test using amino acids is used to detect the presence of drug residues in meat, and the meat is rejected if traces of drugs are found.

Additives can "migrate" into food from the packaging. Inks, dyes and preservatives from cardboard and paper may become part of the food. When glass is re-used, the residues from detergents may find their way into the food product. Small amounts of cadmium and lead will migrate into canned foods. Plastics contain complex mixes of chemicals, many of which can migrate into food. Unreacted monomers, plasticizers, stabilizers and antioxidants all become possible additives. A plastic wrapped cheese slice almost certainly contains plastic which has leached into the fat in the cheese.



As for filth, it's there. Raisins and grated cheese are two good examples. They may include things like metal particles, mammal hairs, mites, insect fragments, wood fragments and filaments from feathers. Fortunately, the fragments are too small to notice. In low doses, the body doesn't notice either.

Food Irradiation

One of the chief reasons for using additives is to preserve food: to delay spoilage due to the growth of moulds or bacteria and to delay sprouting in tuber crops like potatoes. Irradiation is a technology which has been in place for many years, but has never gained widespread public acceptance. Irradiation of food is one of the most effective ways to preserve foods, and leaves no harmful residues.

Although there are solid arguments in favour of food irradiation, there are concerns about its safety. Certainly the public has an aversion to combining "radiation" with anything we ingest. Aside from emotional considerations, there are some concerns that irradiation may be used to disguise poor food storage and processing procedures.

Food Science

The study of food additives is just one small part of an industry which includes a wide range of opportunities. Food scientists may work in any number of enterprises, from agriculture to food processing and medical research. They may be dieticians, nutritionists, chemists, biologists, lab technicians, or other specialists. Food is a necessity, and also a source of great pleasure and fascination. Almost everyone dabbles in food science in their own kitchens. Food scientists make this a life's work.

Suggested Activities

1 Looking Delicious

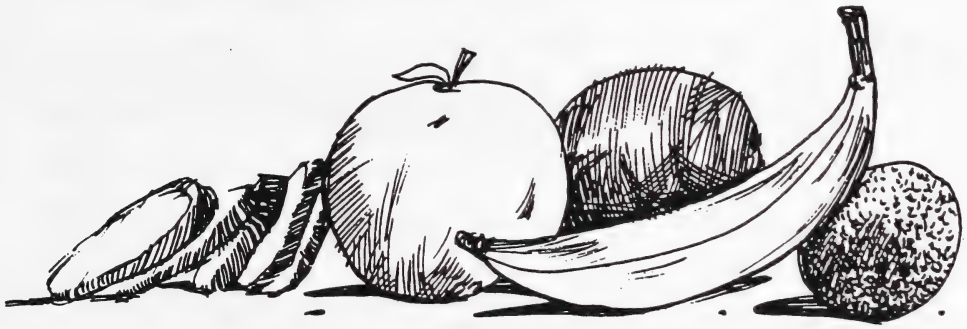
Take four slices from an apple, a banana and a potato, and make four groups which include the three foods. Rub a vitamin C tablet over the surface of the foods in one group. Put some vinegar on the slices in the second group. Put lemon juice on the slices in the third group, and leave the fourth group of slices exposed to the air. Leave the foods for a few hours, and see what happens.

Apples, bananas and potatoes all have enzymes that react with oxygen in the air, and turn the food brown in colour. The untreated slices will turn brown fairly quickly. All the other slices will turn brown much more slowly, or not at all. Why?

Answer

Vitamin C contains ascorbic acid. Vinegar contains acetic acid, and lemon juice contains citric acid. In every case, the acid lowers the pH of the enzyme so that it becomes ineffective. The food therefore becomes oxidized much more slowly, or not at all.

Acid is a food additive which is often seen on processed foods. Lemon juice sprinkled over a fruit salad is a simple example of a common food additive. It is done to enhance the appearance of the food.



2 Label Check

Have students check the label of a processed food, and list and state the purpose of the additives. Note: Many food processing companies now include a 1-800 number on their packaging, and students may have access to additional information through these numbers.

3 Plant Enzymes That Digest Proteins

Meat tenderizers are often used prior to cooking to reduce toughness. This "tough" quality in meat results from the protein **collagen** found within the connective tissue in muscle. The active ingredient of a meat tenderizer is a **proteolytic or protein-degrading enzyme called papain.** The papain enzyme will **hydrolyse** the fibrous collagen as well as muscle proteins into constituent amino acids.

Papain is extracted from unripe papaya, a tropical melon. Other plants contain similar proteolytic enzymes; these include **ficin** from figs and **bromelain** from pineapples.

Problem

To examine the effects of two proteolytic enzymes, papain and bromelain, on proteins. Since it is difficult to directly observe the influence of these enzymes on a meat product, gelatin will be used as the protein substrate. Gelatin is a gel formed from protein molecules. A little green food colouring added to gelatin mixture will improve the visual contrast.

Materials

Fresh pineapple
Canned pineapple rings
Ice bath
Prepared gelatin (i.e., Knox) - 5 dishes per group
Meat tenderizer containing the enzyme papain

Note: One dish of gelatin for each group should be prepared, with meat tenderizer (1/2 tsp.) added just after the boiling water. This dish should be cleary labelled.

Procedure

A. Papain

1. Sprinkle meat tenderizer liberally on the surface of one dish of gelatin. Leave at room temperature for 5 minutes. Note any changes in the surface of the gelatin. Gently poke the surface with a glass rod. Continue to assess the texture at five minute intervals for the duration of the lab period.

2. Using a dish of gelatin that has been thoroughly chilled in a container of ice, repeat the procedure in step #1. Leave the gelatin-enzyme combination on ice for the duration of the lab period.

3. Assess the texture of a third dish of gelatin in which the meat tenderizer was added to the hot gelatin during the preparation phase.

4. Record all observations.
Sample #1 (room temp.)
Sample #2 (ice)
Sample #3 (hot)

B. Bromelain

1. Place a slice of fresh pineapple on the surface of one dish of gelatin and slice of canned pineapple on the surface of a second. Dry each pineapple slice carefully with paper towel before placement.

2. After five minutes, assess the surface of the gelatin. Continue to observe the gelatin at 5 minute intervals for the rest of the lab period.

Note: The liquid observed is not a result of juice from the pineapple.

3. Record your observations_____
Fresh Pineapple
_____
Canned Pineapple

Questions

1. What happens to the structure of the gelatin as protein hydrolysis occurs?

2. Was there any effect of temperature on the action of the papain?

3. What did you observe with the papain added to the hot gelatin? Can you explain your results in terms of the composition and structure of the enzyme?

4. Why do fresh pineapple and canned pineapple react differently?

Answers

1. *Protein network formed in the gelatin is broken down, resulting in loss of the gelatin texture. Water entrapped in the protein network is also released.*

2. *Room temperature is faster. Cold temperature decreases molecular motion and frequency of collision. Enzyme activity is also decreased.*

3. *No effect since the enzyme is denatured by high temperatures.*

4. *Enzyme in canned pineapple is inactivated because of high temperatures reached in processing.*

Source: *Food Chemistry,* M.A.H. Ismond, E.D. Murray Food Science Department, University of Manitoba

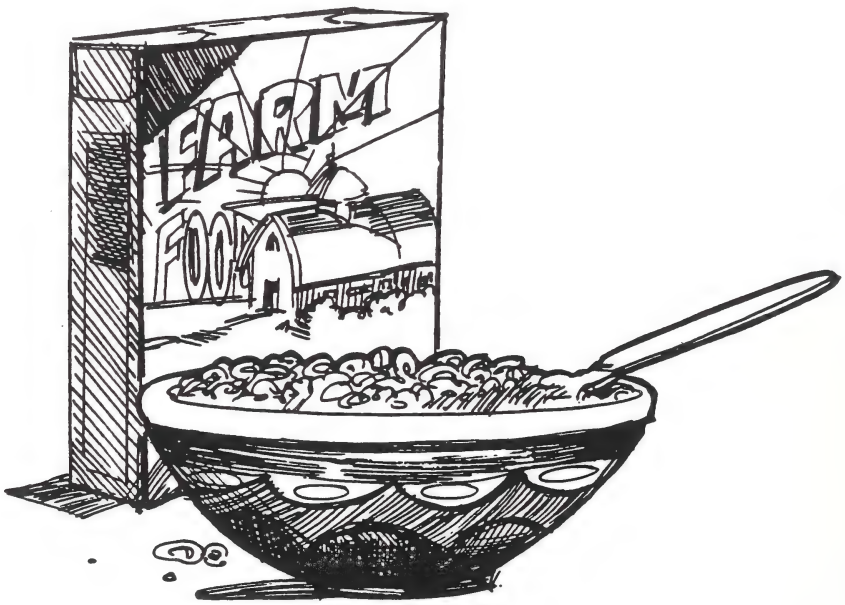
4 Health Cereal vs. Junk Cereal

Compare a box of "healthy" breakfast cereal, such as granola, to a sugary children's cereal. Ingredients and nutritional values will be listed on the package.

Is there a significant difference in nutritional value between the two cereals?

How do the ingredients compare? Compare the sugar content in the cereals. Remember that sweeteners are not always grouped together. They may be listed as sugar, brown sugar, sucrose, glucose (aka dextrose), fructose, corn syrup, and honey. Raisins are also rich in sugar.

Depending on the make of the "health" cereal, students may find there is not much difference between the two.



5 Making Curd

Problem:

To examine the curd from milk prepared by two different chemical methods.

Materials

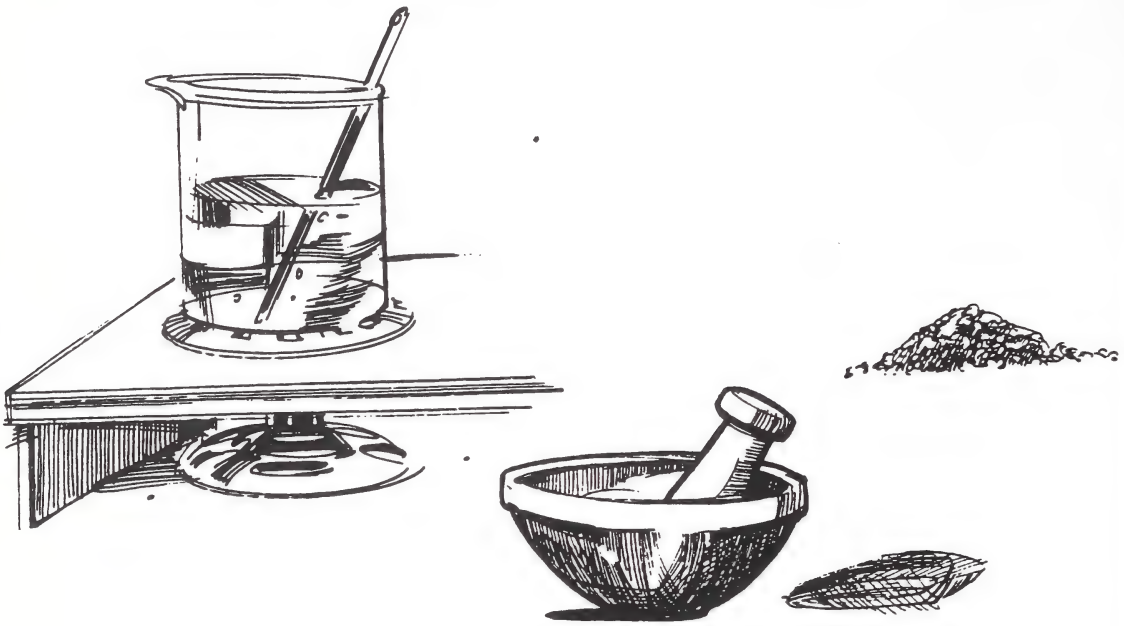
400 mL fresh milk
Junket tablets (for rennin)
Vinegar (5% Acetic acid)
Beakers
Thermometers
Hot plate or bunsen burner
Cheese cloth
Glass rods

Procedure

1. Place 200 mL of milk in each of two beakers.
2. Heat both milk samples to 30°-32° C. Check the temperature with a thermometer. DO NOT OVERHEAT!
3. Crush one junket tablet with a mortar and pestle. While stirring with a glass rod, add half the tablet to one milk sample. Label the beaker.
4. Add 30 mL of vinegar to the other milk sample and stir gently. Label the sample.
5. Gradually increase temperature of both beakers to 38 degrees C., but no higher.
6. Remove the beakers from the heat and allow to sit for at least 15 minutes. Do not disturb the contents.
7. Filter the contents of each beaker through 4 thicknesses of cheese cloth. Your cheese is on the cloth.
8. Press all liquid from the cheeses and allow to dry.
9. Carefully examine the two cheeses for differences in texture.

Questions

1. How do the two cheeses differ in terms of their textural properties? Can you relate the consistency of the acid-based product to any cheese on the market? (*Cheese made with rennin is more elastic. Cheese made with acid is less elastic and more fragile, like cottage cheese.)*



Source: *Food Chemistry*, M.A.H. Ismond, E.D. Murray Food Science Department, University of Manitoba

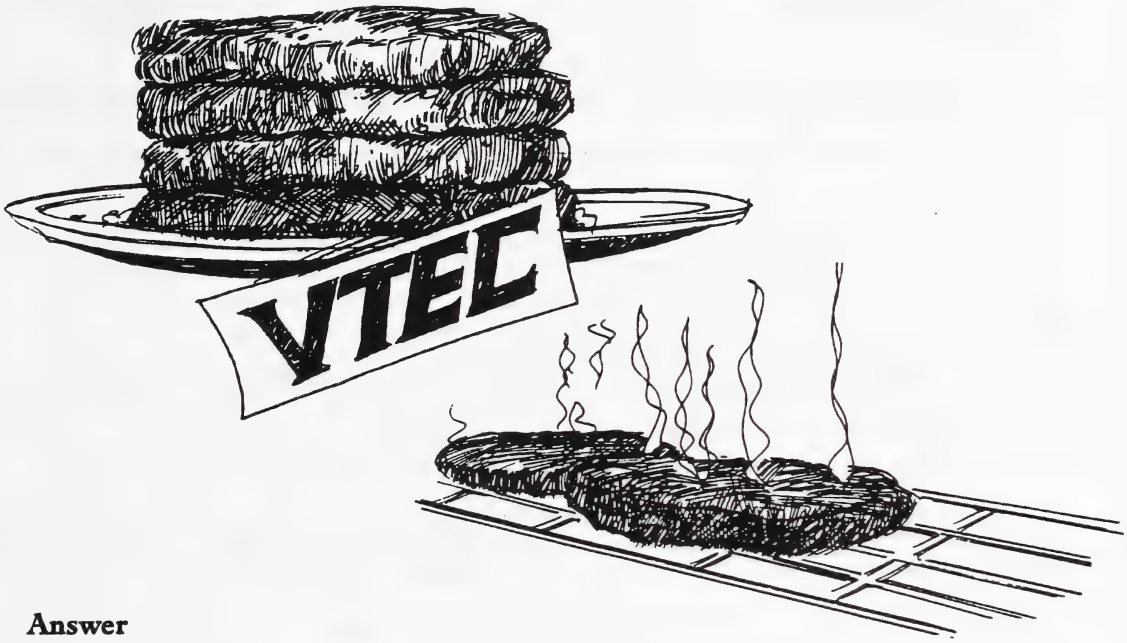
6 Case Study in Food Poisoning

When Jamie's family has a barbecue, they tend to follow the same routine. Jamie's mother mixes up hamburger patties, which she leaves on a plate on the kitchen counter until the barbecue is ready. She does not always wash her hands after handling the raw meat.

Jamie's father cooks the hamburger patties until they are medium-well done. He then puts them back on the same plate used to carry the raw patties.

One week after the last barbecue, Jamie developed diarrhea. After a couple of days, he began to experience stomach cramps and bloody diarrhea. He was taken to the hospital, where tests showed he had a bacteria called VTEC (verotoxigenic E. coli) in his system. Luckily, it did not spread to his kidneys or blood, and Jamie recovered.

VTEC is sometimes known as "hamburger disease" or "barbecue syndrome". Over the past ten years, food poisoning caused by VTEC has increased dramatically. In some cases it leads to kidney failure and even death. How could Jamie's family have avoided this incident?



Answer

VTEC is a bacteria found in unpasteurized milk, poultry, and any ground meat. Hamburger meat is the most common source. Besides avoiding unpasteurized milk, there are safety steps you can take to minimize the risk of infection by VTEC.

- *never leave raw ground meat or poultry at room temperature, as this allows rapid growth of bacteria*
- *wash hands thoroughly after handling raw meat or poultry*
- *use hot, soapy water to wash utensils and plates which have come into contact with raw meat or poultry*
- *wash cutting boards in hot soapy water, followed by a rinse with a bleach solution to destroy bacteria*
- *cook hamburgers until they are well done all the way through*
- *be sure poultry is completely cooked*
- *use a clean plate to carry the cooked meat or poultry*

If you're eating at a restaurant or somebody's home, do not eat pinkish-looking ground meat or poultry. Send it back to be cooked completely, or leave it on your plate.

Note: The fact that unsafe food handling and preparation has never made you sick in the past does not mean you won't be affected in the future.

7 Botulism

Have students research the organism Clostridium botulinum. How is it usually spread, and can you tell if a food is contaminated?

Answer

Clostridium botulinum, the organism that causes botulism, likes to grow where there is no oxygen (jars and cans). It produces a toxin which attacks the nerves and can lead to paralysis and death. The bacteria usually produce a gas and a foul smelling odour, but there are some strains which cannot be detected so easily.

If you find a bulging can, it's wise not to open it. Take it back to the store, or dispose of it in a safe place. Never even taste canned food that is mouldy or has a bad odour. Do not buy dented cans, and do not eat food from cans that appear to be rusted, or damaged in any way. Canned food should be eaten within one year of purchase.*

The greatest risk of botulism in Canada comes from home-canned foods, particularly meats and vegetables which are low in acid. These foods should only be processed in a pressure canner which can reach temperatures high enough to kill the spores of clostridium botulinum.

A safer (and easier) way to preserve food is to store it in a chest type freezer.

**The seams of the can may be damaged enough to let in bacteria, which could contaminate the food inside.*

8 Food Moulds

Have students research food moulds. Is it safe to eat food that has gone mouldy?

Answer

Not a good idea. Some moulds produce mycotoxins which can be highly toxic even in small amounts, and may be carcinogenic. In a liquid or semi-liquid, these toxins may have spread throughout the container. It is safe to cut a small patch of mould off hard cheese, if you cut a good 2.5 cm. beyond the mould.

All moulds are not harmful. The mould in Roquefort cheese is edible, and a mould is used in the production of penicillin. With the exception of Roquefort cheese, consumers can't be sure whether or not a mould is safe to eat.

If you are unsure about the safety of any food, a good rule of thumb is:
"When in doubt, throw it out".

9 Diet

Why is it healthier to eat a wide variety of foods, rather than to eat large quantities of a few foods? If we say that anything eaten in excess is hazardous, can we say that anything is safe if eaten in small amounts?

10 Irradiation

Have students do research into the pros and cons of food irradiation. What is it that prevents this technology from being implemented?

11 Approved Additives

Why is it that additives may be approved in Europe and banned here, or approved here and banned in Europe? Why is saccharin permitted as a sweetener in the United States but not in Canada?

12 Unnecessary Additives

Do we sometimes use additives needlessly? Why is orange cheddar considered desirable, even though cheese is not normally orange?

Recommended Resources

Food Additives: Questions and Answers. Health Protection Branch, Health and Welfare Canada, 1990

Food Additive Pocket Dictionary. Health Protection Branch, Health and Welfare Canada, 1990

Various pamphlets on foods and food safety available from the Health Protection Branch.

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Food Safety–It's All In Your Hands. Minister of Supply and Services, 1993.

Health Risk Determination: The Challenge of Health Protection. Minister of Supply and Services Canada,1990.

ACCESS NETWORK

EXTREME

Science Technology & Society

CLOSE-UP

To the Teacher

This video is intended for students in junior and senior high school who are using the microscope to study basic cell structure. The video shows how microscopy began and how the technology has evolved in recent years. By looking at the work of various scientists, we see applications for compound light microscopes, transmission electron microscopes, scanning electron microscopes, and the very new confocal laser microscope.

The video offers insights into how various models of microscopes work. It shows previously hidden worlds which scientists are bringing into ever sharper focus under the powerful eye of the microscope, and emphasizes the growing importance of microscopes in many fields.

Overview of *Extreme Close-up*

In 1938, two students at the University of Toronto, Albert Prebus and James Hillier, put together the first working model of the transmission electron microscope in North America. This represented a major evolution in the science of microscopy: one that scientists have been steadily building on ever since.

The electron microscope's ability to magnify specimens thousands of times has enabled us to study many aspects of the molecular world around us. Microscopes have become indispensable in almost every type of work—from food processing to police forensics, micro-surgery, and geological surveys. Microscopes extend the human eye, helping us to understand and explain natural phenomena.

This production should give students an appreciation for the capabilities of modern microscopes, their importance to society on a number of levels, and the many new frontiers that are opening up using microscopic research.

We look at the compound light microscope that is used in high school labs and see the role this

instrument plays in more advanced research. We explore the capabilities of two types of electron microscope: the **transmission electron microscope**, and the **scanning electron microscope**. And we take a look at the latest development in light microscopes: the **confocal laser microscope**.

The video shows how science and technology advance hand-in-hand. For example, more powerful microscopes were developed as scientists gained a better understanding of light and electrons. Viewers will meet various scientists who work with microscopes, and see how these people are using advanced microscopic technology to achieve specific goals.

Microscopes

Early Microscopes

Glass was first manufactured in Egypt in 2000 B.C., and its magnifying powers may even have been recognized that long ago. We do know that at the time of the Roman empire, people were using lenses to magnify objects. By the 1200s, crystal lenses had been designed for use as spectacles. This was the beginning of a new branch of physics, known as **optics**. About 400 years later, lenses were put to new uses with the first versions of the telescope and compound light microscope.

In 1609, Galileo constructed the first astronomical telescope, which he used to study our solar system, and the stars around us. About 50 years later in Holland, an amateur scientist named Anton van Leeuwenhoek began experimenting with microscopes. In the course of his studies he made more than 200 microscopes, some of which were able to magnify specimens 270 times their original size. Van Leeuwenhoek was the first person to observe and document living cells. He called the single celled organisms he observed "animalcules". He also studied capillary circulation and red blood cells. The lenses used in early microscopes distorted the image so it was difficult to get a clear picture of cell structures.

The telescope and microscope are similar in that they both use lenses to enlarge the image of objects. The telescope magnifies distant objects, bringing the image closer to the human eye. The microscope magnifies tiny objects, making them appear larger so they can be seen by the human eye.

Resolution

The ability to magnify an object is one aspect of microscopy; **resolution** is the other equally important aspect. **Resolution** is the ability to recognize two objects as being distinct from one another and to **resolve** the distance between them: in other words, the ability to distinguish fine detail.

The human eye has a resolving power of about 0.1 mm. This means that the human eye can distinguish two objects as being separate from one another if the space between them is at least 0.1 mm.

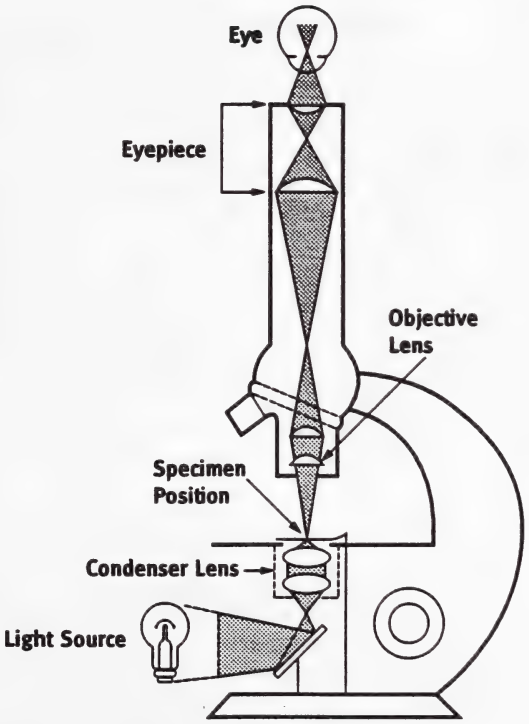
Resolution in the electron microscope is measured in **nanometres**. One nanometre is equal to one billionth of a metre.

Compound Light Microscope

At the same time that Anton van Leeuwenhoek was working with single lens microscopes, Robert Hooke, a 17th Century English scientist, constructed the first compound light microscope. The compound light microscopes found in every modern science lab operate in much the same way as Hooke's early models. Two lenses are used to enlarge the image. The *ocular lens* is close to the observer's eye, and the *objective lens* is close to the specimen. There are usually three objective lenses: low, medium and high. The objective lens magnifies the specimen itself, and the ocular lens magnifies that image.

A compound light microscope can magnify an object about 1000 times its normal size, with good resolution.

Compound Light Microscope

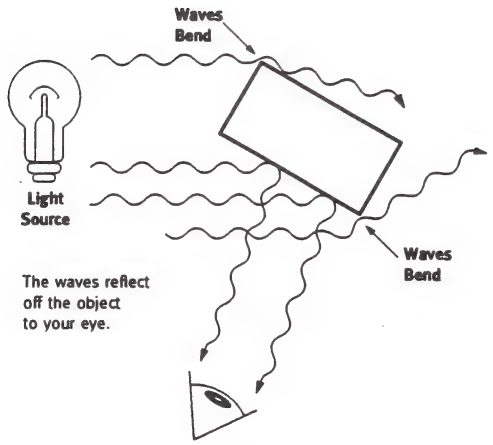


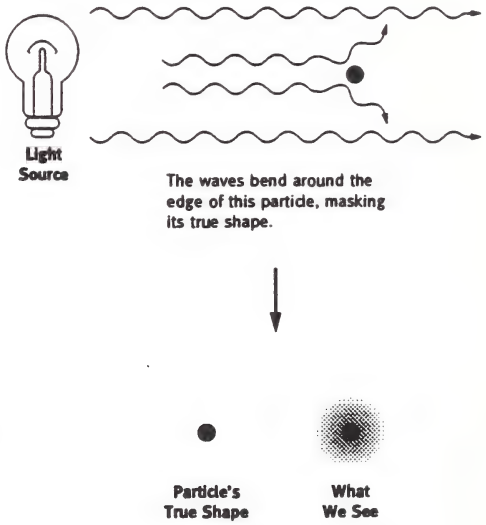
Light Waves

Light is a wave, and has a certain wavelength. When giving an image of an object, light microscopes are limited by the wavelength of the light. We are able to see things because light waves are reflected off objects, and then enter our eyes. When something is smaller than the wavelength of the wave striking it, the wave will bend around the edge of the object. This bending of the wave causes interference, which can mask the object's true shape, and limit resolution. The wavelength of visible light is between 400 to 750 nanometres. If we want to see something smaller than the wavelength of light, we must use another source with a shorter wavelength.

Electrons exhibit wave properties similar to visible light, but the wavelength of the electron is far shorter. While the wavelength of visible light is 400 to 750 nanometres, an electron wavelength is less than 0.1 nm. Therefore electron wavelengths are 4000 to 7000 times smaller than light wavelengths, depending on the voltage. (The higher the voltage, the shorter the wave.) This means that electrons enable us to resolve objects which are not visible using light.

Limits to Resolution





You can't resolve anything smaller than the wavelength of the illumination source.
(λ = wavelength)

visible light: λ = 400-750 nm
(1nm = 1 billionth of a metre)

electrons: λ = 0.1 nm (approx.)

Electron wavelengths are 4000-7000 times smaller than light wavelengths, so electrons can resolve things that are many times smaller.

Electron Microscope

An electron microscope uses electrons rather than light to image a specimen. Although work was being done on the electron microscope in Europe in the 1930s, two Canadian scientists made North America's first working model in 1938. A similar model was built in the United States in 1939. Since then, the technology of electron microscopy has continually advanced.

Electrons are tiny subatomic particles that reside around the nucleus of an atom. In a **transmission electron microscope (TEM)**, a high voltage current removes outer electrons from a Tungsten atom, and accelerates the electrons down the column and through a very thin section of a specimen. Because the wavelength of electrons is so small, even molecules in air would interfere with the electron beam. For this reason, the electron beam must travel through a vacuum in the microscope.

The higher the voltage used to accelerate the electrons down the column of the microscope, the shorter the electron wavelength. Electron microscopes use an accelerating potential of between 20,000 to 1,000,000 volts.

When a charged particle moves through a magnetic field, its direction of motion can be altered. For this reason, electromagnets are used to focus the beam, just as lenses focus light waves in a compound light microscope. This enlarges the image produced by electrons when they strike a fluorescent screen, or a photographic plate if a permanent record of the image is needed.

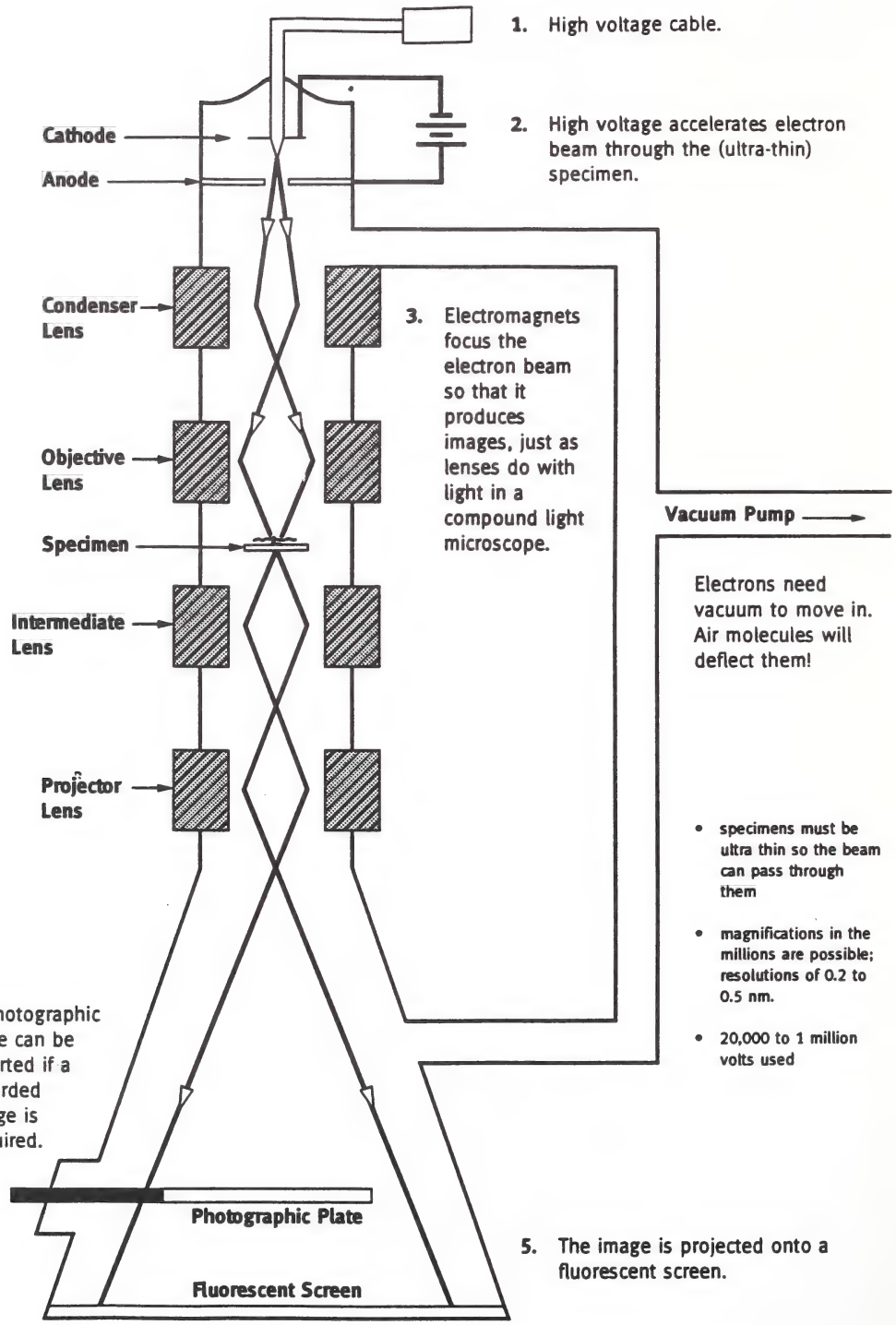
The transmission electron microscope transmits electrons right *through* the specimen, giving an image of the internal structure of the cell. Because cells are electron dense, the specimens must be sliced very thin. Specimens are mounted in a plastic embedding material for ease of cutting.

Electron waves are too short to be visualized by the eye. Therefore a phosphor-coated screen, much like those used in the first television screens, is placed in the path of the electrons. The phosphor is activated by the electrons as they strike the plate, and visible light is emitted, giving an image on the plate of the electron density of the sample. The electrons which do not penetrate the sample do not contribute to the image.

The lack of contrast in the image produced by a transmission electron microscope can be a problem; therefore an electron dense stain is often applied. Reading the image accurately is a skill that comes with experience.

The first transmission electron microscope was able to magnify samples 7000 times. Today's models are capable of magnifications greater than 300,000 times, and a resolution of between 0.2 and 0.5 nm.

Transmission Electron Microscope (TEM)


1. High voltage cable.
2. High voltage accelerates electron beam through the (ultra-thin) specimen.
Cathode
Anode
Condenser Lens
Objective Lens
Specimen
Intermediate Lens
Projector Lens
3. Electromagnets focus the electron beam so that it produces images, just as lenses do with light in a compound light microscope.
Vacuum Pump
Electrons need vacuum to move in. Air molecules will deflect them!
• specimens must be ultra thin so the beam can pass through them
• magnifications in the millions are possible; resolutions of 0.2 to 0.5 nm.
• 20,000 to 1 million volts used
4. A photographic plate can be inserted if a recorded image is required.
Photographic Plate
Fluorescent Screen
5. The image is projected onto a fluorescent screen.

Scanning Electron Microscope (SEM)

Developed in the 1970s, the SEM scans the surface topography of a specimen, producing a three dimensional image on a screen.

An electron beam is produced just as it is in the transmission electron microscope. The electrons are then passed through a series of magnetic lenses that focus the beam to a very fine point, 10 nm or less in diameter. This fine point of electrons, called a scanning probe, scans the surface of the specimen. The electrons reflected from the specimen, along with electrons released from the surface of the specimen, are captured by an electron detector and the number of electrons is counted. As the beam scans across the surface of the specimen, an image is formed. The brightness of any given point in the image is based upon the number of electrons counted at the corresponding point on the specimen. The image is viewed on a display unit very similar to a television screen. Since the number of electrons emitted depends on the surface features of the specimen, a three dimensional picture of the specimen can be produced.

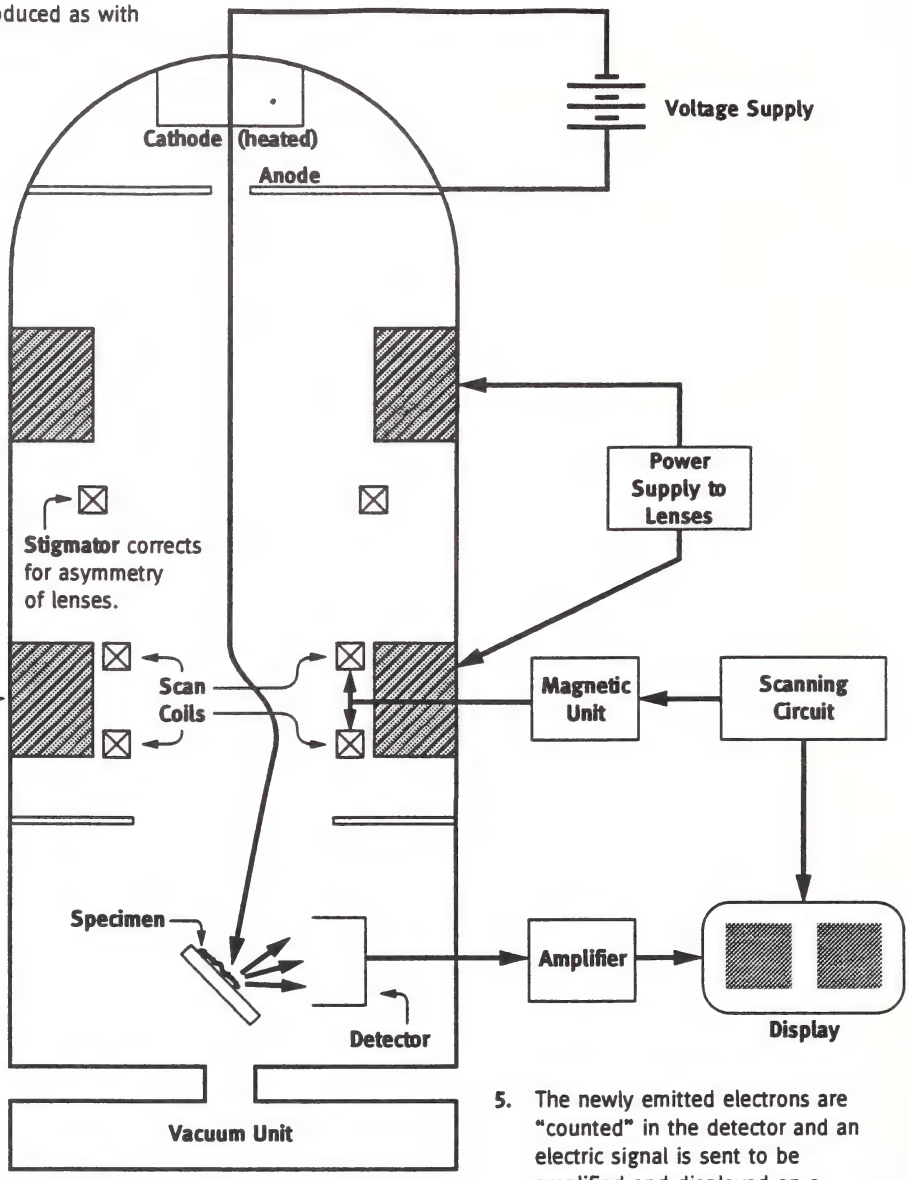
A scanning electron microscope can magnify a specimen to approximately 300,000 times. Its resolution and magnification are not as good as that of the transmission electron microscope, but improvements are constantly being made.

Earlier models of the scanning electron microscope used a high accelerating voltage to achieve maximum resolution, which could destroy biological specimens. Specimens were coated with particles of gold so they would conduct electrons from the sample, decreasing the sample destruction. But even though the gold coating was only 10 to 50 nm thick, it sometimes interfered with the viewing of fine biological structures. Using low voltage electrons, without special equipment and techniques, decreased the resolution.

But technology is improving. Current development includes a **low accelerating voltage** scanning electron microscope with **high resolution** scanning. This instrument gives an accurate image of the specimen without distortion caused by metal coating, and without destroying the specimen.

The two microscopes complement each other in many fields. For example, with the transmission electron microscope one is able to locate bacteria within cells, while the scanning electron microscope will show the area where a bacterium interacts with the cell. This allows researchers to study important details in host-pathogen interactions.

1. Electron beam produced as with TEM.



2. Electromagnetic condenser lens concentrates the beam.

3. Scan coils direct the beam back and forth across the specimen much like an electron beam scans across a TV screen.

4. When the beam hits the specimen, more electrons are ejected according to surface features.

5. The newly emitted electrons are "counted" in the detector and an electric signal is sent to be amplified and displayed on a monitor.

   The scanning circuit sends signals to the scanning coil (electromagnets) *and* to the display unit. This keeps the display monitor in sync with the scanning of the surface.

Scanning Tunnelling Microscope

The idea for the scanning tunnelling microscope has been around since the early 1900s, but only recently has the technology been in place to make it work. The first scanning tunnelling microscope was made in 1981 by two researchers at an IBM lab in Zurich. The researchers, G.K. Binnig and H. Rohrer, received the Nobel prize in 1986 for their work.

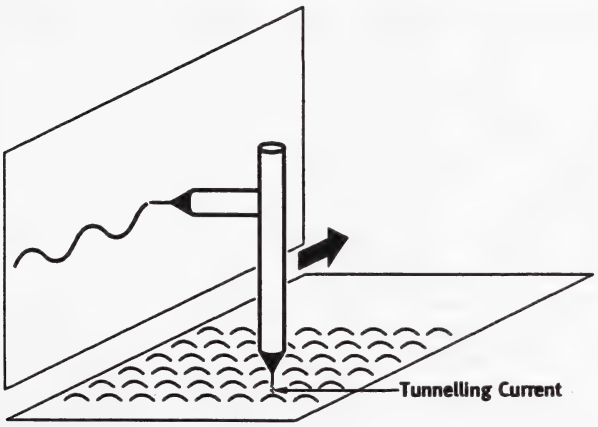
A probe on the scanning tunnelling microscope scans the surface of a specimen, sensing the distance between its tip and the surface. These distances are recorded and converted into a magnified image that is displayed on a screen. The image shows only the surface topography of the specimen.

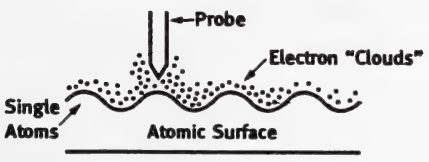
The probe of a scanning tunnelling microscope has a tip that is only one atom thick. A differential voltage is applied between the probe and the surface of the specimen. The tunnelling of the electrons from the surface to the probe gives rise to a tunnelling current, which is relative to the distance between the surface and the probe. The image which results can show surface details of atomic size.

Today scanning tunnelling microscopes are used extensively in the computer industry. They can, for example, show the exact crystal structure of the surface of a silicon chip. This may lead to the development of even smaller chips in the future.

These microscopes are now used on an experimental basis in other sciences, such as biology.

Scanning Tunnelling Microscope (STM)*





1. Surface is scanned with a probe sensing the distance between its tip and the surface. The distances are recorded.

2. The probe's tip is nearly as small as one atom thick. The electrons at the surface of the atoms of the object to be scanned are located according to a probability distribution (dots). A "tunnelling current" occurs between the probe and the surface. The strength of this current varies with distance from the probe to the surface, and with the electron structure of the material involved.

* Invented in 1981 by G.K. Binnig and H. Roher at an IBM lab in Zurich. They won the 1986 Nobel Prize for it. Designed for looking at atomic surfaces.

* Can show details as small as one atom.

Confocal Laser Scanning Microscope

The confocal laser scanning microscope is a very recent breakthrough in the technology of microscopes. It allows scientists, by means of **optical sectioning**, to look within a cell, and examine different sections without cutting or damaging the specimen. It is therefore ideal for studying live specimens. The principle is similar to a scanning electron microscope, except that it operates with light rather than electrons.

Although objects smaller than the wavelength of visible light cannot be seen, this disadvantage is more than compensated for by the fact that the specimen can be viewed alive, and that sections of the specimen can be viewed as well.

A laser produces a beam of light which is directed to scanning mirrors. The beam is focused through microscope lenses, and scans the specimen. The specimen can be stained with fluorochromes, substances that fluoresce when excited with a certain wavelength of light. The beam excites the fluorochromes in the specimen. Light emitted from the excited fluorochromes travels back and is focused through a pinhole near the lenses' focal point (the confocal point). Photomultiplier detectors convert light to an electric signal which can be stored and manipulated. The signal is then converted into an image by a computer, which also controls the scanning of the sample.

Because it can be used to view live specimens, the confocal laser scanning microscope has great potential in biology, zoology, and medical research.

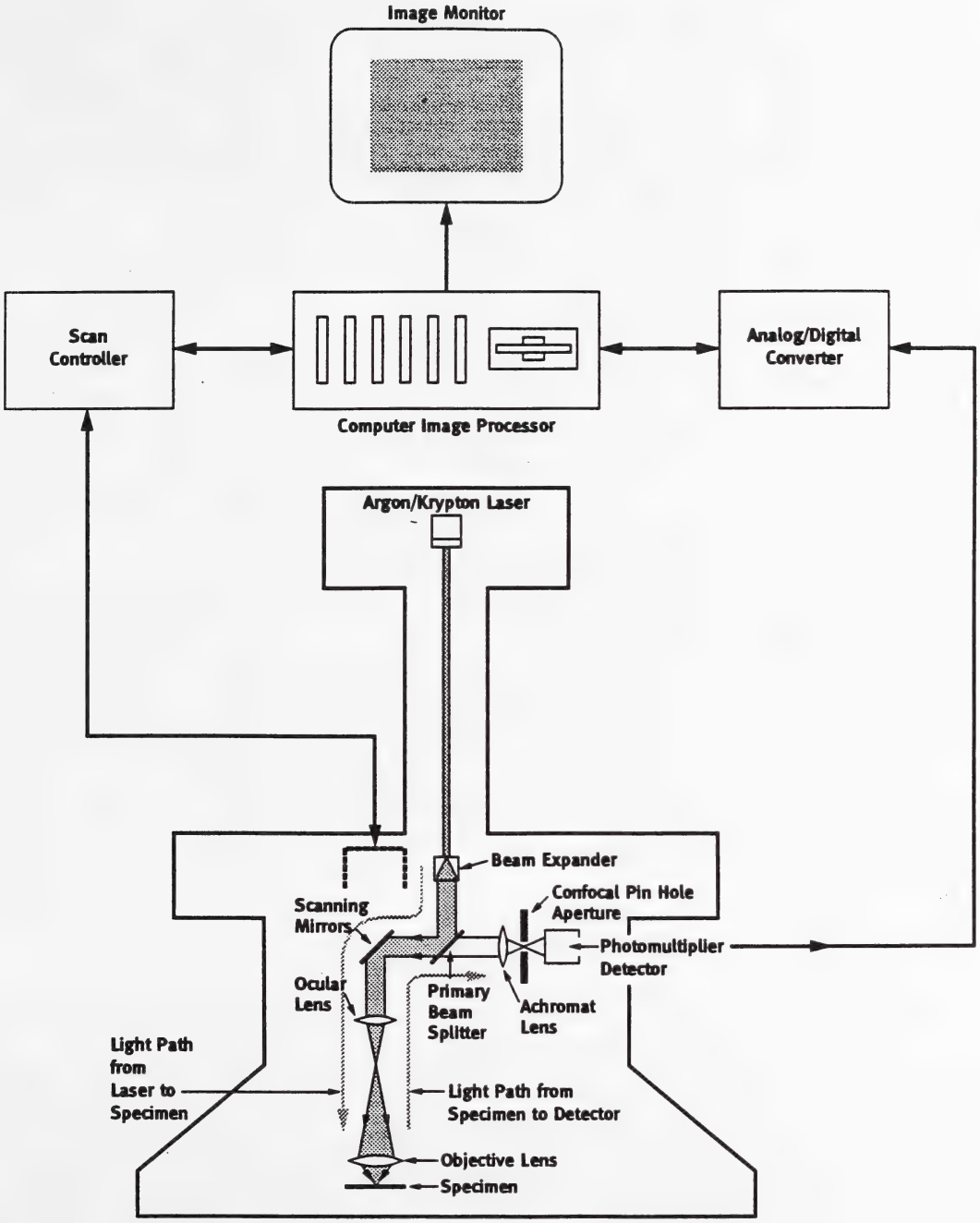


Image Monitor
Scan Controller
Computer Image Processor
Analog/Digital Converter
Argon/Krypton Laser
Beam Expander
Confocal Pin Hole Aperture
Scanning Mirrors
Photomultiplier Detector
Ocular Lens
Primary Beam Splitter
Achromat Lens
Light Path from Laser to Specimen
Light Path from Specimen to Detector
Objective Lens
Specimen

The Scientists

Dr. David Cass and Lory Sanders

David Cass, a biologist at the University of Alberta, and Lory Sanders, a student, rely on microscopes for their research and studies. In this program, they demonstrate how different microscopes can be used to reveal different perspectives on the structure of plant cells. Taking a section of leaf from a young pea plant, they examine it under a compound light microscope, transmission electron microscope, scanning electron microscope, and confocal laser microscope.

Before the specimen is viewed, it must be properly prepared, and this requires different procedures for the different types of microscope. Specimens are sectioned by a microtome, which is like a mini meat-slicer that cuts off extremely thin sections. Preparation for viewing under a compound light microscope involves "fixing" the specimen in paraffin, and staining it. Specimens must be imbedded in plastic for viewing under electron microscopes.

Dr. Cass explains that the **compound light microscope** is the basis for all microscopic work. Looking at the section of pea leaf under a compound light microscope, we can see the epidermal tissue, the underlying mesophyll cells and nuclei within these cells, as well as chloroplasts, mitochondria, and xylem. In order to have a look *within* the cells, we go to the transmission electron microscope.

The **transmission electron microscope** reveals the contents of cells. Under this microscope, we have a much closer view of the pea leaf specimen. Dr. Cass and Lory Sanders point out several interesting features, including the cell walls, two chloroplasts and the nucleus between them, vacuoles, Golgi apparatus, ribosomes, and a channel connecting one cell to another.

The **scanning electron microscope** gives us only the surface topography of the pea leaf specimen. It does not reveal images beneath the surface. Along with many of the organelles seen earlier, we can also make out guard cells. These are specialized epidermal cells that regulate gas exchange in a plant, allowing the plant to take in carbon dioxide and release oxygen.

In demonstrating the **confocal laser microscope**, Dr. Cass and Lory Sanders show how the microscope can optically section a specimen. This allows scientists to study any cross-section within a specimen, without having to physically cut it. For scientists who study living tissue, the confocal laser microscope marks a tremendous advance in technology. The ability to manipulate colours on the screen is an added asset in identifying various plant cells and their components.

Richard Sherburne and Dr. Diane Taylor

Richard Sherburne is a scientist in the field of Medical Microbiology and Infectious Diseases at the University of Alberta. His lab includes compound light microscopes, a transmission electron microscope, and a very advanced model of the scanning electron microscope. This scanning electron

microscope is a low-voltage, high-resolution model that enables scientists to look at small biological structures, such as those arising from interactions between cells and pathogens.

Dr. Diane Taylor is a medical microbiologist who, along with colleagues at the University of Alberta, has been researching a bacterium that causes stomach ulcers. This is one of the many projects that Richard Sherburne is working on, using the microscope.

The ulcer-causing germ has been identified as the *Helicobacter pylori* bacterium, and has proven to be the cause of some, but not all, stomach ulcers. Scientists at the university are trying to discover what combination of antibiotics will be most effective in eliminating the bacteria. If the bacteria are not completely eliminated, the ulcers will eventually flare up again.

For Richard Sherburne, the *Helicobacter pylori* bacterium presents an intriguing and familiar problem. This bacterium is able to hide between cells, and remain dormant for years between flare-ups. Similar behaviour is suspected in the bacterium that causes pertussis, or whooping cough.

With the scanning electron microscope, Richard Sherburne can study the behaviour of the bacterium. By observing how it attaches itself to cells and hides within cells, he can gain a better understanding of how to treat this problem.

"Know your enemy" is a maxim for waging war on the battlefield and in the lab. The electron microscope allows scientists to study the previously hidden world of bacteria and viruses. When they can see how a pathogen interacts with healthy cells, scientists have a much better chance of finding a way to eliminate the pathogen.

Applications for Microscopes

As microscope technology becomes more advanced, the number of applications for this technology increases. Electron microscopes are used extensively in many industries, including the following:

Agriculture
- genetic engineering in developing new varieties of crops
- research into biological controls for pests

Computers and Advanced Electronics
- designing circuits
- constructing computer chips
- locating breaks in micro-circuits

Construction and Engineering
- examining metals for fatigue and stress fractures
- studying soil composition to assess stability

Food Research
- studying the microstructure of foods
- analyzing changes that occur when foods are processed

Geology and Mining
- studying the crystal structures of rocks and minerals.

Microscopes also play a vital role in many non-industrial areas:

Medical Research
- studying cell changes in diseases such as cancer
- diagnosing blood and viral diseases
- studying behaviour of bacteria and viruses

Every other field of scientific research
- studying the cellular and molecular structure of matter

Police Investigative Work
- DNA fingerprinting

Environmental Monitoring and Pollution Control
- analyzing the chemical compounds in air and water
- studying the effects of pollution on plants and animals

As microscopes become more refined, the list of possible applications expands. Both light and electron microscopes hold great potential for scientific research and discoveries. In the near future, light microscopes may be powerful enough to reveal viruses. The opportunity to study live viruses under a microscope, and see how they interact with healthy cells, would be a major step forward in medical research.

Despite the fact that scientific knowledge is increasing at unprecedented rates, scientists still have much to learn about plant and animal cells, bacteria, viruses, and the molecular structure of matter. Microscopy provides a path into unknown worlds, and holds tremendous potential for future scientific discoveries.

Suggested Questions for Research and Discussion

Forensic Science – Background

Forensic science is the collection and analysis of evidence found at the scene of a crime. Forensic scientists may specialize in any number of areas: enforcing environmental regulations, enforcing fishing and hunting regulations, or investigating criminal offenses in cooperation with the police department, fire department, or customs officials. A forensic scientist prepares reports for investigators. These reports become part of the case and may be used as evidence in court.

1. As part of the police investigative team, how would you use a compound light microscope to analyze evidence found at the scene of a crime? The evidence includes samples of hair, blood, fabric, and paint chips.

   Many different technologies are used in police forensic work, including gas chromatography, infrared spectroscopy, X-ray diffraction, and microscopy. A compound light microscope is used to examine samples of hair, blood, fabric and paint chips. A fairly low power is usually enough to reveal important evidence.

2. What is DNA fingerprinting, and how does it work?

   A far more sophisticated type of analysis is used to further identify the blood and possibly the hair samples. This is called "DNA fingerprinting". It represents the most significant advance in police work since conventional fingerprinting was developed.

   Scientists can take a tiny sample of tissue, blood, body fluids such as semen, or hair, if the root (the living portion) is intact, and establish a DNA fingerprint. An individual's DNA has a unique arrangement of nitrogen bases. In the laboratory, scientists take the DNA, cut it into smaller pieces with an enzyme, and transfer them to a nylon sheet. They then tag the DNA fragments with a radioactive probe that identifies the unique sections of the molecule. The nylon sheet is placed against X-ray film, and black bands appear where the radioactive probe has attached itself to the nitrogen bases. The result is similar to the bar code used on merchandise.

   Only identical twins will have the same arrangement of nitrogen bases in their DNA. If DNA from a sample taken at the scene of the crime matches a suspect's DNA, this would be enough evidence for a conviction in court. A DNA fingerprint provides positive identification of a suspect.

3. Do you need an electron microscope to produce a DNA fingerprint?

   DNA fingerprinting is a chemical procedure, and does not require an electron microscope. The discovery of DNA through the

electron microscope led to the development of this procedure.

4. How is an electron microscope used in police forensic investigations?

   A scanning electron microscope is used in police forensics when investigators need to study very tiny fragments of material. For example, a ***gunshot residue analysis*** *involves taking swabs from the skin of a gunshot victim and a suspect's hands, and analyzing these under the scanning electron microscope. Heavy metals such as barium, antimony, and arsenic are present in gunpowder. The scanning electron microscope can identify tiny particles of heavy metals, and an X-ray spectrometer analyzes these particles to identify their composition.*

   When a suspect is found at the scene of a crime, swabs from the suspect's hands or gloves may prove that person fired a gun.

   The scanning electron microscope is also used to analyze tiny fragments of glass or metals, which may match tools or objects found at the scene of a crime.

Medical Science – Background

Physicians depend on laboratory work to assist them in diagnosing and treating patients. Medical researchers rely on microscopes to study the behaviour of bacteria, viruses, and healthy cells.

1. How is the compound light microscope used in blood analysis?

   Blood consists of plasma, which contains formed components such as erythrocytes (red blood cells), and leukocytes (white blood cells). Red blood cells supply and transport oxygen and carbon dioxide throughout the body and to and from the cells.

   White blood cells are divided into several categories. Some assist in clotting. Others function as a defense mechanism, destroying and mopping up foreign invaders. While the functions of several types of white blood cells are known, the role of others is not fully understood. Doctors can, however, obtain useful information from analyzing blood specimens under a light microscope.

   For example, during the course of infection there is a shift in the type of white blood cells which predominate in the blood stream. In many types of infection, especially bacterial, the total number of white blood cells increases. Some diseases cause a decrease in white blood cells. Using a microscope, scientists can calculate the percentage of each kind of white blood cell compared to a normal count. This helps the doctor determine what the cause of infection may be, and what treatment should be taken.

   The infectious agent itself may be seen in the blood sample under a light microscope, and identified by shape, size and staining characteristics.

   The presence and concentration of specific antibodies in the serum can also help the doctor to diagnose the illness.

2. Why are electron microscopes needed in order to conduct

more intensive medical research?

An electron microscope is able to achieve a much higher magnification. Many viruses and bacteria are too small to see using a compound light microscope, but can be seen using an electron microscope.

Some bacteria are able to elude the normal host immune system by invading cells and remaining within the intracellular environment for long periods of time, causing chronic long term infections. Examples of such bacteria are Mycobacterium tuberculosis, *the causative agent of tuberculosis (TB), and* Mycobacterium leprae, *the causative agent of leprosy.*

The electron microscope is often used to find the location of infectious particles within the cellular environment.

3. How does a scanning electron microscope complement the transmission electron microscope?

   A low-voltage, high-resolution scanning electron microscope enables researchers to study the surface topography of a specimen. The specimen may be sectioned to reveal bacteria hiding within a cell. Using the scanning electron microscope, researchers can see the manner in which bacteria attach themselves to a cell. This interaction between bacteria and body cells may provide scientists with a key to eliminating the bacteria.

4. A confocal laser microscope does not have the resolution of an electron microscope. Why is it considered to be such a breakthrough in technology?

   The confocal laser microscope has a unique ability to optically section a specimen. Scientists can take a piece of living tissue, and look at any cross-section of it without having to physically cut the specimen. It's possible to look at the layers inside a living cell without damaging the cell. The confocal laser microscope has great potential in biology and medical science.

Scanning Electron Microscopes – Pros and Cons

1. Is it possible for a scanning electron microscope, or a scanning tunnelling electron microscope to reveal what is beneath the surface of a specimen?

   No. The scanning electron microscope gives only the surface topography. Because the microscope scans only the surface, it shows an accurate picture of how the organism would appear to the human eye if we were able to see it. The scanning tunnelling microscope is valuable in the computer industry because it can be used to check the tiniest of semiconductors for flaws. It scans only the surface topography of the equipment.

Further Challenge

Have students select a science or enterprise which interests them. Ask them to research how recent advances in microscopy have affected work in this area.

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AFTER ..... THE ..... FLUSH

Science Technology & Society

ACCESS NETWORK

AFTER THE FLUSH

To the Teacher

There's good news, and there's bad news. Every new technology, medical treatment, business enterprise, or construction project comes with its own list of positives and negatives: benefits and risks.

This video program is aimed at students in Grades 11 and 12 who are studying chemistry, biology, physics, or integrated sciences. It may also be of interest to grade 10 students. The program gives viewers a unique perspective on **risk/benefit analysis**, showing how the process can be applied to the problem of sewage sludge disposal. Although the subject matter is presented in a humorous way, the underlying message is serious.

Waste management is a common dilemma in urban areas, and therefore a problem that may be applicable to the viewers' own towns or cities. Viewers will see that it is important to look at the situation from different perspectives, and to analyze the associated risks and benefits. Whether we're talking about construction of a dam, location of a landfill site, or any number of other contentious issues, proponents and opponents all have strong opinions and convincing arguments. Issues are usually not simple and do not lend themselves to definitive solutions. Right and wrong depend on your point of view, and most "solutions" are a compromise.

Besides the broad topic of risk/benefit analysis, teachers can use the video as a resource for studying the science involved in sewage treatment. This is a natural biological process that relies on oxygen, gravity, aerobic and anaerobic bacteria, temperature controls, and the conversion of organics to biogas. Sewage sludge has a chemical composition that makes it valuable as a fertilizer, but it also contains disease-causing micro-organisms.

Objective

The video demonstrates the complexities of effective planning and decision-making. It shows the importance of weighing quantitative and qualitative risks and benefits before embarking on any new project. Viewers should be encouraged to become informed about issues, and to use their knowledge to arrive at rational decisions.

Overview of *After the Flush*

The king in our mythical kingdom would rather pass the hours exercising and improving his golf game than dealing with serious issues. However, his advisor insists that one particular problem must be confronted: the kingdom is producing too much sewage sludge, and is running out of places to dispose of it.

The king and advisor realize there are different options in disposing of sewage sludge, and they must make a decision about which route to take. They decide to rate each option in terms of fixed criteria. The three criteria are:

- **cost,**
- **environmental impact,** and
- **marketability of the end product.**

Later, they add a fourth criterion: "Emotional Response".

They narrow down their choices of disposal methods to four options. The four options are:

- **farm spreading,**
- **composting,**
- **heat processing,** and
- **irradiation.**

Four representatives of the different options come to the palace. Each one argues in favour of a particular option, and tries to persuade the king and advisor to choose that method of disposal. After all the presentations have been made, the king is left with the realization that there is no such thing as a simple solution.

Background Information

Risk benefit analysis can be applied to any number of problems, but this video deals with the disposal of sewage sludge ... a problem which should be seen in the larger context of waste management.

Only two or three generations ago, most people lived on farms. Today, the majority of the population lives in cities. One result of this demographic change is that we have great amounts of garbage to dispose of, within concentrated areas.

The subject of waste disposal is fraught with emotion and controversy. There is no ideal spot on this planet to locate a landfill, and we desperately need more sites. With dumps across Canada getting close to capacity, people are looking at alternative ways to deal with garbage. Each alternative has advantages and disadvantages.

Sewage sludge is part of urban waste, and its safe disposal is part of the on-going problem of waste management. When hundreds of thousands, or millions, of people live together in a city, the amount of sewage sludge quickly adds up.

Where Does Sewage Go?

Sewage treatment involves separating solid from liquid waste. Waste water from the city is flushed through pipes to the sewage treatment plant. First it flows into grit tanks. Air is circulated to keep organic matter suspended while sand and gravel settle to the bottom. This is scraped out and taken to the landfill. Paper, sticks, plastics and debris that float to the top are also taken to the landfill.

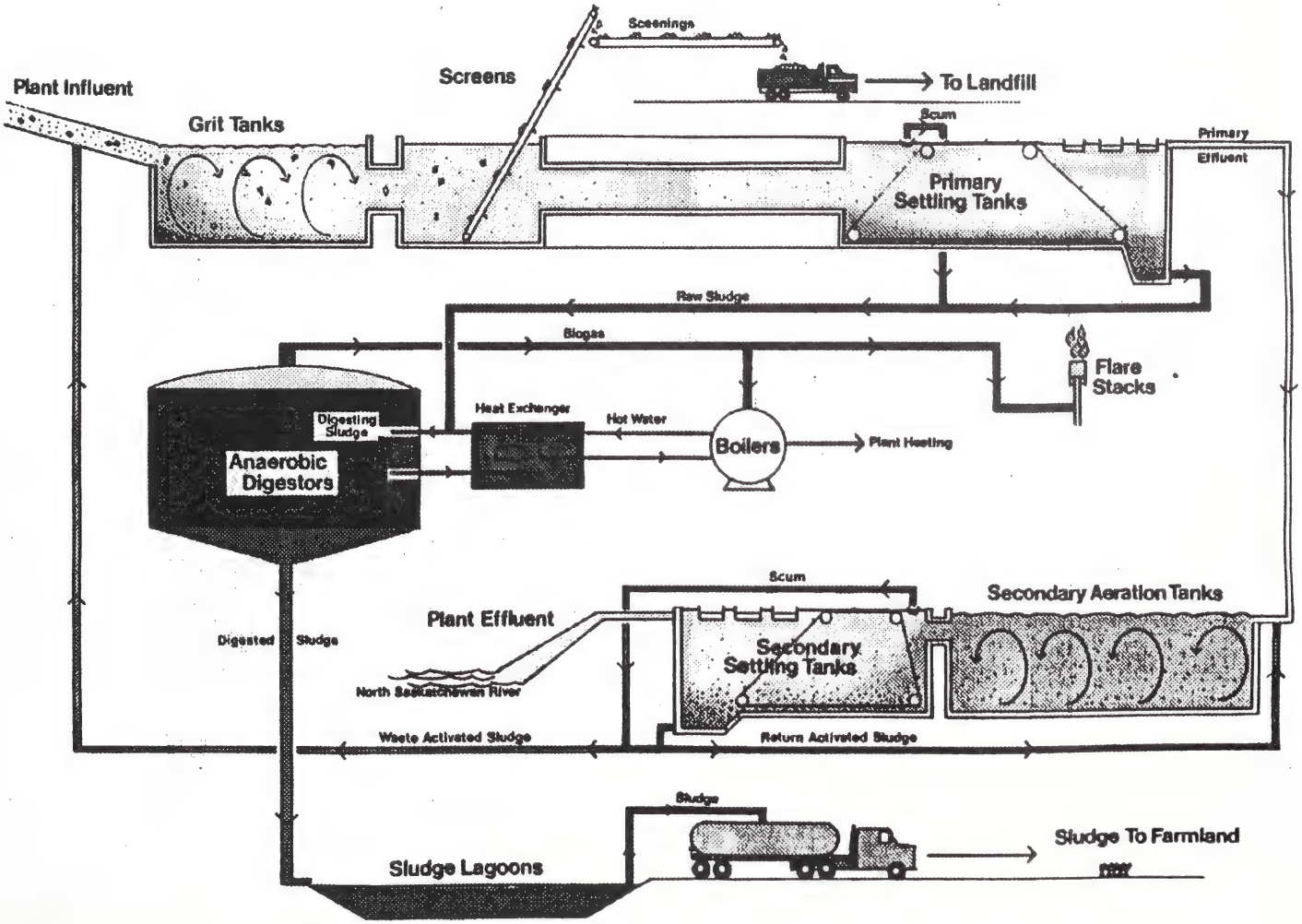
The waste water now passes into settling tanks. Organic matter settles to the bottom of the tanks and forms a substance called "sludge". Oil, grease, and lighter materials float to the surface. Mechanical scrapers collect this sludge and scum from the bottom and top of the tanks.

This process is called primary sewage treatment. The water, which is now called primary effluent, flows into aeration tanks for secondary treatment. In the aeration tanks, micro-organisms feed on organic matter in the water. The water then flows into final clarifiers (settling tanks) before it is discharged back into the river. This treated water has 96 to 97 per cent of suspended matter and organic pollutants removed. The process takes about twelve hours.

Organic material that has been removed from the water is piped into a machine called an anaerobic digester. Inside this digester, anaerobic bacteria go to work on the sludge. (Anaerobic means they can work without oxygen.) Decomposing material goes through certain stages. First, acid-producing bacteria break down the organics into short-chain (volatile) fatty acids. Methane-producing bacteria then convert these acids to biogas. Biogas, which contains methane, is collected and used to heat the sewage treatment plant. Any excess gas is burnt off at the plant.

It takes about 15 to 20 days for sludge to pass through the digester. During the process of decomposition, some of the liquid separates out, and the volume of sludge is reduced by one half.

A City Waste Water Treatment Plant



Digested sludge is pumped to open lagoons, where it remains for several years. A city of half a million people can produce about 20,000 tonnes of dry sludge per year.

The sludge is high in phosphates and nitrogen, and therefore has value as a fertilizer. However, its use must be regulated. Treated sludge still contains harmful micro-organisms, including bacteria, viruses, and intestinal parasites. Depending on the city, the sludge may also contain heavy metals and other toxic wastes.

PART I: Sewage Sludge Disposal Methods

Farm Spreading

Farm spreading is a process used by many cities to dispose of large amounts of sewage sludge. During the growing season, tanker trucks remove sludge from the lagoons in a slurry of about ten per cent solids, and transport it to farmland. The trucks then spread sludge over the fields.

The farmer must work the soil within 24 hours of spreading, in order to bury the sludge. For three years, the field cannot be used for root crops or grazing, because of the possible transmission of pathogens. However, it is fine for growing grain crops. Pathogens will biodegrade in the environment. After three years, they will have reached the end of their life cycle, or will have been destroyed by sunlight or other bacteria. At this point, the land can be used for any crop.

Sewage sludge can only be spread on farmland under certain conditions:

- soil must be workable (not frozen)
- land must be relatively flat, to prevent run-off
- groundwater must be a good depth under the soil, to reduce the risk of contamination
- land must not be used for root crops or grazing for three years
- sludge must not have high concentrations of heavy metals or toxic chemicals.

Advantages

Farm spreading is an environmentally sound use for sewage sludge. The sludge is not only disposed of, but it actually improves the quality of farmland. As well as fertilizing the soil, sewage sludge acts as a soil conditioner. Organic matter in sludge improves the soil's capacity to hold water.

Disadvantages

Although this program is popular with farmers, the land adjacent to a city is quickly used up. Sludge must then be trucked longer and longer distances away from the sewage lagoons, and this adds to the cost.

Farm spreading is very dependent on weather. If the ground is too wet, trucks can't get onto the fields. Because the schedule for spreading cannot be determined in advance, farmers often wait several weeks for a shipment, and sometimes must wait until the next season. They put up with this inconvenience because the sludge is free. It is not possible to charge farmers for the sludge, so

the city must assume transport and spreading costs.

The schedule for spreading is limited to the growing season. The program can handle only about 50% to 70% of the city's total sludge output.

There are some aesthetic and health concerns associated with farm spreading. However, these are not serious. Odours can be kept to a minimum if the soil is worked immediately after spreading. Careful selection of sites means that run-off problems and groundwater contamination can be avoided.

Sludge with high concentrations of heavy metals or toxic chemicals may not be suitable for spreading.

Composting

Composting is a natural process of decomposition, and is becoming more popular as a method of waste disposal. The final product of the composting process is humus, which is the organic constituent of soil formed by decomposed plant and animal material. Composting is going on all the time in the wilderness; matter rots, due to the activities of living unicellular organisms such as bacteria, and multicellular organisms such as insects and worms. In backyard or large urban composting facilities, this natural process is speeded up by keeping the compost moist, and turning it frequently so that wastes are exposed to the air.

Rapid decomposition also requires a proper balance between carbonaceous materials and nitrogenous matter. This is commonly referred to as the carbon/nitrogen ratio, or the C/N ratio. The ideal C/N ratio for effective composting is 25 parts carbon to one part nitrogen. The final humus product should have a C/N ratio of about 10 parts carbon to one part nitrogen.

The carbon ratio of some common materials to one part nitrogen is as follows:

grass clippings	25
oak leaves	50
manure	23
vegetable scraps	25
pine needles	100
sawdust	150 *to* 500

A large scale urban composting facility will require that waste materials be monitored to achieve the right proportions of carbon to nitrogen and moisture. Sewage sludge, because it is low on carbon, can comprise only a small portion of the total waste product. The waste must be at least six parts carbonaceous material to one part sludge.

When microbes digest carbon compounds, the carbon is converted to carbon dioxide, or oxidized. Part of this energy is given off in the form of heat. Energy is therefore a by-product of decomposition. Certain types of bacteria thrive in warmer temperatures, and it is generally true that matter will decompose more rapidly in warmer temperatures. High temperatures also kill pathogens. For reasons of efficiency and hygiene, large scale composting should be carried out in warm climates or in an indoor facility with temperature control.

The complexity of the composting process depends on the quantity and types of waste that are being composted. Grass clippings and other garden wastes are relatively easy to compost. With moisture, time, a little added soil, and an occasional stir to let in oxygen, these materials will decompose.

Many other waste products could also be handled in a composting facility. When a city initiates large scale composting, homeowners and businesses are asked to separate their garbage into wet and dry bags. Materials in the dry bags are recycled if possible, and the wet bags go to the composting plant. Wet bags from residential areas can include the following:

- kitchen waste
- wet and soiled papers
- diapers and sanitary products
- pet wastes

Non-residential products which can be composted include the following:

- animal manure
- waste from feed lots
- waste from packing plants
- wood chip waste
- newspaper products
- phone books
- sewage sludge

Some of these materials include pathogens, which are undesirable in the final product. All disease-causing organisms such as bacteria, viruses and intestinal parasites *should* be killed in the composting process. This means that the waste must be kept at 55.9 degrees Celsius for 72 hours.

Large scale composting is being carried out in some cities, and other cities are studying the possibilities. Cities in the southern United States, such as Los Angeles and Dallas, have a climate that makes outdoor composting practical. Penticton, B.C., composts waste outdoors, but only March to mid-December. Because Penticton is a small city (about 50,000 people), the volume of waste is not great.

Advantages

Organic materials take up a great deal of space in a landfill, and large scale composting offers an effective alternative. Much of a city's garbage can be disposed of through composting, and the end product can be put to use as a soil enricher, possibly in land reclamation projects. Composting is a natural process, and is an environmentally friendly option for disposing of wastes.

Disadvantages

Although composting is a good method for disposing of many waste products, it cannot handle large quantities of sewage sludge. It is therefore not a solution to the sewage sludge disposal problem. As a method for disposing of other organic wastes, composting has some drawbacks.

Canada's climate is cold for much of the year, and, with the exception of composting yard wastes in summer, large Canadian cities do not have the outdoor composting option. Indoor composting facilities involve a great deal more expense.

Any large scale composting operation will have problems with odours. A composting facility should therefore be located well away from residential areas. Although an indoor plant may be designed so that odours inside the plant are not released into the air, there are still odours from raw waste before it enters the plant.

Pathogens are also a concern. The product can be used as a soil conditioner, but there are restrictions on its application. Most cities do not offer compost for use by the general public because of the possibility that some pathogens may have survived the composting process. The product is typically used by spreading it in forested areas to enrich the soil, or

by using it in land reclamation at old mining sites.

Heavy metals and toxic chemicals in sludge can pose a problem. If these are present in the raw ingredients, they will still be present in the humus. Effects on the environment can be minimized by dispersing the composted material over a very wide area.

PART I: Suggested Activities

1. Sewage effluent is sometimes used to irrigate farmland, by spraying, sprinkling, or simply pumping it onto the fields. Areas that use effluent irrigation report crop yields 20% higher than areas using local surface water. Most harmful micro-organisms are killed by exposure to strong sunlight, high temperatures and dry weather. What are the advantages and disadvantages of irrigating with effluent?

   Advantages

   - Less need for costly fertilizers
   - Less costly to use untreated water for irrigation instead of drinking water

   Disadvantages

   - Effluent sometimes contains high concentrations of salts, which will accumulate in the soil and make it less productive.
   - Some micro-organisms may survive. Effluent cannot be used on crops which are eaten raw, or on crops such as corn, where the leaf structure could harbour micro-organisms.
   - Run-off from effluent could pollute groundwater or nearby bodies of water. Land must be carefully selected so that the effluent will not pollute the environment.

2. Experiment with composting, comparing different organic materials to see how readily they break down. An example would be to compare a pile of grass clippings with a pile of pine needles. Introduce variables such as temperature, light, air and moisture, and observe their effects.

3. Start a composting project at school, by composting all scraps from the cafeteria and from student lunches. Yard wastes from the school grounds could also be included.

4. Investigate the sewage sludge disposal methods in your community. Is the sludge being handled in a responsible manner? Is there a problem with excess sludge?

5. The characteristics of sludge will determine whether or not it is suitable for land application. The typical composition of municipal sludge in Alberta is shown in the table on the following page.

Characteristics of Sludges

Composition of Alberta Sludge as Percent of Dry Weight (unless otherwise noted)*

	Min.	*Max.*
Solids	1.0	20
TKN* **	1.0	11
Ammonia Nitrogen	0.02	4.1
Phosphorus (total)	0.25	2.3
Calcium	1.2	6.6
Magnesium	0.37	1.7
Sodium	0.002	3.4
Potassium	0.17	1.1
Iron	0.17	2.5
Manganese**	80	1000
Zinc**	390	1400
Copper**	280	1300
Lead**	50	1750
Nickel**	16	100
Cadmium**	4	20
Chromium**	22	1700
Boron**	7	33
Mercury**	1	6

* *Sludge is dried to remove all water before analyses are done.*

** *Parts per million on a dry weight basis*

*** *Total Kjeldhal Nitrogen*

Sludges may also contain disease-causing viruses, bacteria and protozoan and helminthic (worm) parasites.

Which components can be used by plants as nutrients?

Which components are considered to be heavy metal toxic wastes?

Which component could potentially harm human health if incorporated into a food crop from soil treated with sludge?

NOTE: Kjeldhal Nitrogen measures ammonia plus organic nitrogen. Ammonia Nitrogen can be subtracted from TKN to arrive at the component for organic nitrogen.

SOURCE: Sewage as a Resource, Alberta Environment.

PART II: Sewage Sludge Disposal Methods

Heat Processing

This process for treating sludge is also sometimes referred to as heat drying. It takes place inside a building, and uses heat to reduce the sludge into a dry, stable product. The heat is produced by burning methane, natural gas, or propane. *(See illustration, page 11)*

Wet sludge is brought into the plant by augers, or on a conveyer belt. Inside the drying chamber, a radiant plate is heated by burners. The plate can reach temperatures of 1200 degrees Celsius.

Gas and steam from the sludge are taken off separately, so that emissions from the processing are not released into the atmosphere. The gases are incinerated, and the vapour is condensed. Waste water from this condensed vapour is sent back to the sewage treatment plant.

The resulting product is a very dry substance, which looks and feels like hard granules of dirt. It is odourless and free of pathogens. Eighty to ninety per cent of the water content has been removed, so the quantity of sludge is greatly reduced. Heat processed sludge is a relatively inert product that does not break down readily in water. Over the years it may add some nutrients to the soil, but it does not have real value as a fertilizer.

Advantages

Heat processing is an indoor option, and is therefore not restricted by local climate conditions. By removing about 90% of water from the sludge, this process greatly reduces the volume of sewage sludge, so there is far less product to dispose of.

The very high temperatures used in heat processing ensure that all pathogens are killed.

Emissions from the process are treated within the facility, so there is no release of waste products into the atmosphere. If a heat processing plant is located right at the sewage lagoons, there are no added odour problems.

Disadvantages

Initial costs for constructing the plant are high. Once the plant is operating, there are continued costs for fuel to heat the burners. Because heat processing depends on very high temperatures, these fuel costs would be significant.

Although emissions from the sludge are contained within the plant, there will be emissions from the burners themselves, which are vented separately.

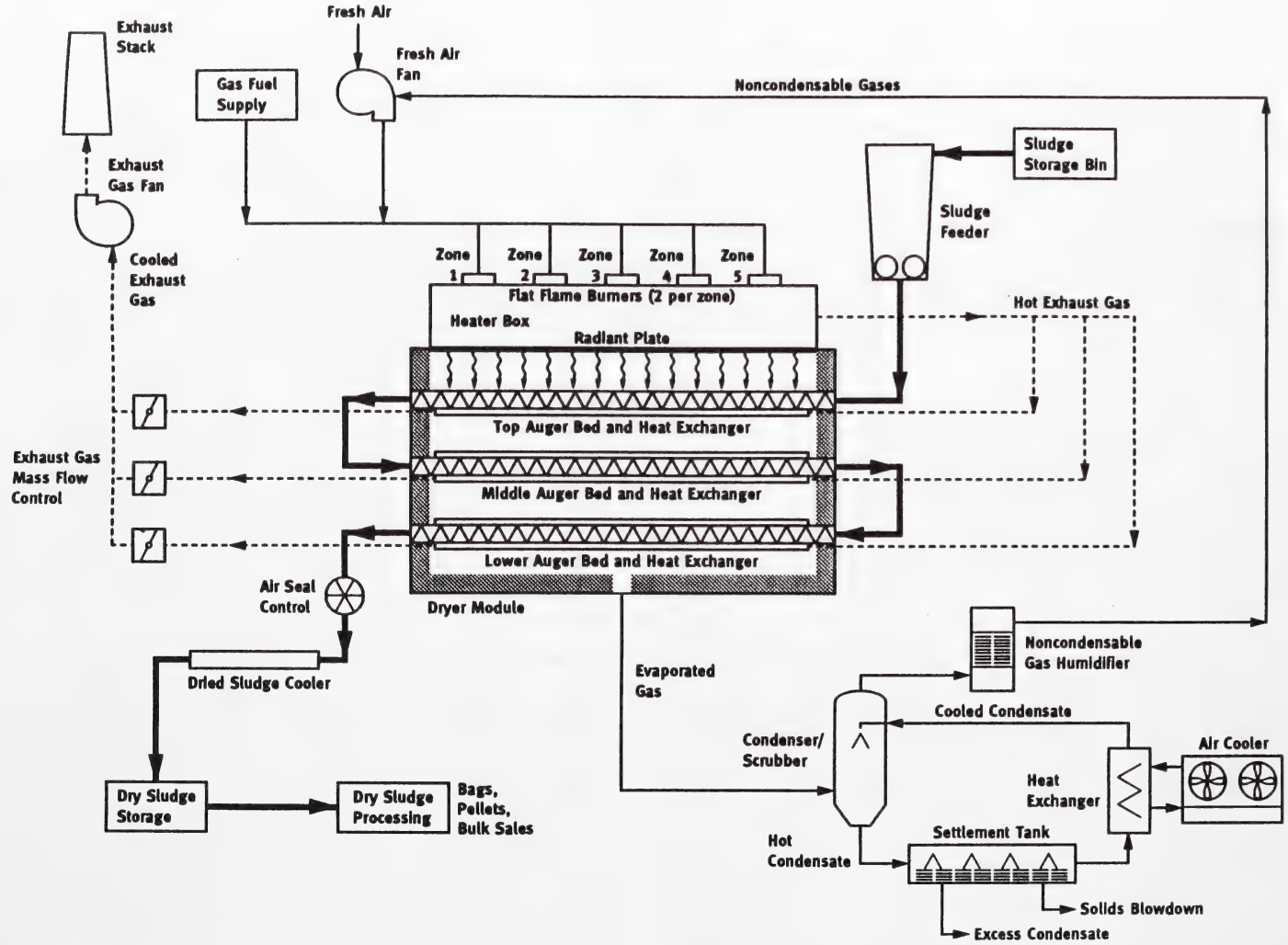
There is no market for the granules of dried sludge; however, finding a place to dispose of them should not be a problem.

Irradiation

Irradiation of sewage sludge is a new concept in North America, although it has been practised in Germany for some time. The process of irradiation has been around since the late 1940s, and Canada has a great deal of expertise in this area.

Irradiation is used extensively in industry, in the production of pharmaceuticals, pharmaceutical

Radiant Plate Dryer–Process Model



supplies, medical supplies, cosmetics, and many other products.

Irradiation is also used in hospitals to sterilize medical equipment and supplies, and to disinfect blood products for patients with low immunity. Radiation therapy is used to treat some cancers. Nuclear magnetic resonance imaging is a diagnostic procedure which employs radiation.

For many years, irradiation has been seen as a potential method for preserving food, by slowing the growth of moulds and bacteria. This use, however, has not been widely accepted. Many food packages are irradiated as a method of sterilization, as are wine corks.

Waste disposal is a potential new market for irradiation plants. As well as processing sewage sludge, irradiation could be a way to sterilize international waste from air and sea ports, and to safely dispose of medical wastes.

How It Works

Irradiation technology is fuelled by cobalt 60, a radioactive isotope. Cobalt, as mined from the earth, is a natural metallic element. It is called cobalt 59 because it has an atomic mass of 59. Thin pencils, or rods, of cobalt 59 must be treated in a nuclear reactor. Inside the reactor, they are bombarded with neutrons for a period of two or three years. At the end of this time, about 10% of the cobalt 59 atoms have been transformed into cobalt 60, and the rods are ready for use.

$$^{59}_{27}Co + ^{1}_{0}n \rightarrow ^{60}_{27}Co + Y$$

Cobalt 60 emits gamma rays — a form of high energy electromagnetic radiation. The usefulness of radiation depends on its ionizing power and penetrating power. Gamma rays can easily penetrate any substance, with the exception of several centimetres of lead or very thick concrete. When the gamma rays penetrate a substance they create electrically charged ions which break up the molecular structure of organisms within the substance. Because of this chemical change, the organisms are unable to reproduce, and they die.

Cancer cells are more active metabolically than normal cells. For this reason, cancer cells are more susceptible to damage from ionizing radiation. In cobalt radiation therapy, the cobalt source is swung around the body in a circular arc, with the beam focused on the cancerous tumour. The tumour receives gamma radiation continuously, while surrounding healthy tissues are only briefly exposed to radiation. Gamma rays alter cancer cells so they are unable to reproduce.

The most widespread use of gamma radiation is in sterilizing products. Because gamma rays have such high penetration power, they can sterilize a product right through the packaging.

Gamma radiation does not make the product radioactive. It is safe to handle immediately after irradiation. No nuclear wastes result from the irradiation process. When cobalt 60 rods lose their strength, they are replaced. The old rods are taken back to the nuclear plant where they can be charged up again for re-use.

Irradiation of Sewage Sludge

Before it comes into the irradiation plant, sewage sludge is spun in a centrifuge to remove some of the water and then air-dried. Between 40 and 50 percent of the moisture should be removed prior to

irradiation. Sludge is taken in on a conveyer belt. The cobalt 60 rods are raised from their water storage tank, and the sludge is exposed to gamma radiation. Irradiated sludge leaves the plant on the conveyer belt and is bagged for sale.

All pathogens are killed when the soil is irradiated. Because sludge is exposed to the radiation for only a certain length of time, some vegetative bacteria will survive the process. This means that the end product is not completely inert. Beneficial bacteria produce organic compounds which inhibit the growth of disease-causing microbes. These bacteria allow the irradiated sludge to maintain a healthy microbial balance so that the product cannot easily be contaminated.

Irradiated sludge is a dry, disinfected, soil-like fertilizer product that can be sold to gardeners, nurseries, landscapers, golf courses and farmers. It acts as a soil conditioner, similar to peat moss, and also adds some nutrients to the soil.

Advantages

A major economic advantage in this process is the potential market for irradiated sludge. The product can be packaged in plastic bags, and should have a market value of about $100 per tonne.

The irradiation plant will not affect the environment with any harmful emissions.

All the sludge can be treated, leaving no surplus of sewage sludge.

Costs of running the plant are not high. The energy expense is in replacing the cobalt 60 rods. Although this is expensive, the rods have a long life span.

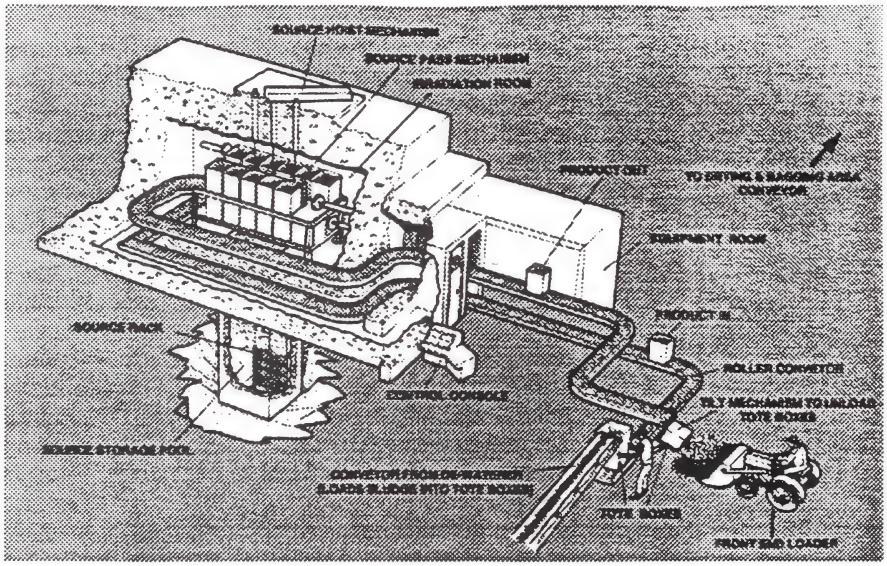
Cobalt 60 shipments would take place once a year. The rods are transported inside specially designed containers able to withstand accidents, earthquakes, fires and other stresses. If one of the containers should somehow break open, the rods would present a danger only to the people retrieving them.

The plant itself is very safe, with concrete walls almost two metres thick. Water in the storage tank absorbs gamma rays but does not retain them. The water is safe to drink. In the very unlikely event that a plant broke apart, the only danger would be in actually handling the cobalt 60 rods. Workers wearing protective gear would have to do this.

Disadvantages

The public is wary about any process which involves nuclear energy and radiation. Although nuclear technology is used in hospitals and many industries, it is possible for people to ignore such small facilities. A plant to treat sewage sludge would be larger than the typical hospital irradiation unit, and people are fearful of larger scale nuclear technology. The nuclear disaster at Chernobyl, in Ukraine, has increased people's fears about the industry.

Before sludge is taken into the irradiation plant, it has to be de-watered and then air dried. Air drying requires space where the sludge can be spread out in the open, and turned. This is not possible in cities that experience heavy amounts of rainfall and high humidity. In these areas, all the de-watering would have to be done mechanically.



As with the other methods, irradiation does not affect the heavy metal or toxic chemical content in sewage sludge. Cities that have toxic chemicals and/or high concentrations of heavy metals in their sludge would not be able to offer the product for sale to homeowners.

Other Options

New ideas and advances in technology add a further uncertainty to the decision-making process. The four options outlined in the video are not the only possible methods for dealing with sewage sludge, but they are the strongest contenders. There are, however, other possibilities.

One is to combine sewage with lime and cement kiln dust, and sell it as a soil conditioner. The lime should kill all the pathogens, but tests indicate that some pathogens may survive the process. This method also doubles the volume of sewage sludge, and the product is worth only about $10.00 per tonne.

A recent proposal for dealing with sludge involves blasting it through a snow-making machine, and using it as artificial snow. The company that came up with this technique claims that the quick freezing action of the snow maker kills pathogens. This technique is being studied, but there are some concerns that pathogens would survive the process.

It does, however, raise another problem. A city may invest in one method, only to find that a few months later a simpler, less costly, and more efficient method has become available.

Risks and Benefits

Problems like the safe disposal of sewage sludge do not lend themselves to easy answers. Risk/benefit analysis is one system people use in trying to grapple with complex issues. A thorough

risk/benefit analysis is a complex process, which involves measuring quantitative and qualitative risks and benefits in the hope of reaching an informed conclusion. This kind of disciplined approach helps to ensure that everything has been included that should be weighed in the analysis. People have to decide how much they are willing to risk losing—or how much gain they should insist on, in order to accept a given risk.

Although risk benefit analysis helps people to make informed decisions, it is not a black and white, absolutely accurate procedure. It is very difficult to put a value on people's lives, or on improved health. Yet these are factors that have to be included in the analysis.

The amount of risk people are willing to accept also varies widely. The public's perception of a risk may differ from the scientific community's perception of the same risk. People are more willing to accept risks if they feel that they have some control over the situation, and if the risk is a familiar one. Driving a car carries a fairly high level of risk, but people tend to look at this as part of life. It is familiar, and they feel they have some control over the situation.

"People accept risks from activities such as skiing that are about 1000 times as great as they would tolerate from involuntary hazards such as preservatives in food."

("Perception of Risk", *Science Magazine*. P. Slovic, April 17, 1987.)

While a thorough analysis takes into account as many factors as possible, there is no way of being totally accurate. When we look at a particular problem, we try to list the pluses and minuses for each alternative. But the lists can never be complete, because there are too many unknowns. Often the items are impossible to measure, and the future impact will not become really clear until far into the future.

By applying risk benefit analysis to a problem, we can become more aware of the complex layers that are involved and the possible ramifications of any course of action. The analysis should help us to reach an informed decision, but it does not allow us to see into the future. The actual outcome may still come as a surprise.

Part II: Suggested Activities

1. Imagine you are living in the early 1900s. How would you assess the risks and benefits of the automobile from that perspective? How would a risk/benefit analysis of the automobile from today's vantage point be carried out?

2. The city of Victoria has received negative publicity because of their practice of discharging sewage into the ocean. Groups in other cities have protested by cancelling plans to hold conventions in Victoria. The city is not treating its sewage because of cost, and because some scientists believe the ocean's ecosystem can easily handle the amount of sewage released. Discuss the wider implications of this approach to sewage disposal.

3. Nitrites can react in the stomach to produce carcinogenic nitrosamines. Despite this, nitrites are commonly added to cured meats as a food preservative. They prevent the growth of the *Cloristidium botulinum* spores, which produce a dangerous food poisoning known as botulism.

   The botulism micro-organism is the most deadly poison known on earth. Five grams of the toxin would be enough to kill more than one billion people.

   Nitrates occur naturally in many foods, and combined with the bacteria in saliva, they produce nitrites. This means that even if nitrites were eliminated from all cured meats, people would be cutting out only about 22% of their total consumption of nitrites.

   Using this example, discuss with students how a risk/benefit analysis may justify the use of a known carcinogen as a food preservative.

4. Many people engage in practices in their daily lives that carry high risks, even though they are aware of those risks. What factors lead people to justify these actions? Look at this problem in terms of the following practices:

   - taking steroids to enhance appearance and athletic abilities
   - sun tanning
   - riding motorcycles
   - bicycling without a helmet
   - smoking cigarettes

Recommended Resources

1. Alberta Environment publication, *Sewage as a Resource*.

2. Various publications on waste management available from provincial environment departments and municipal waste treatment facilities

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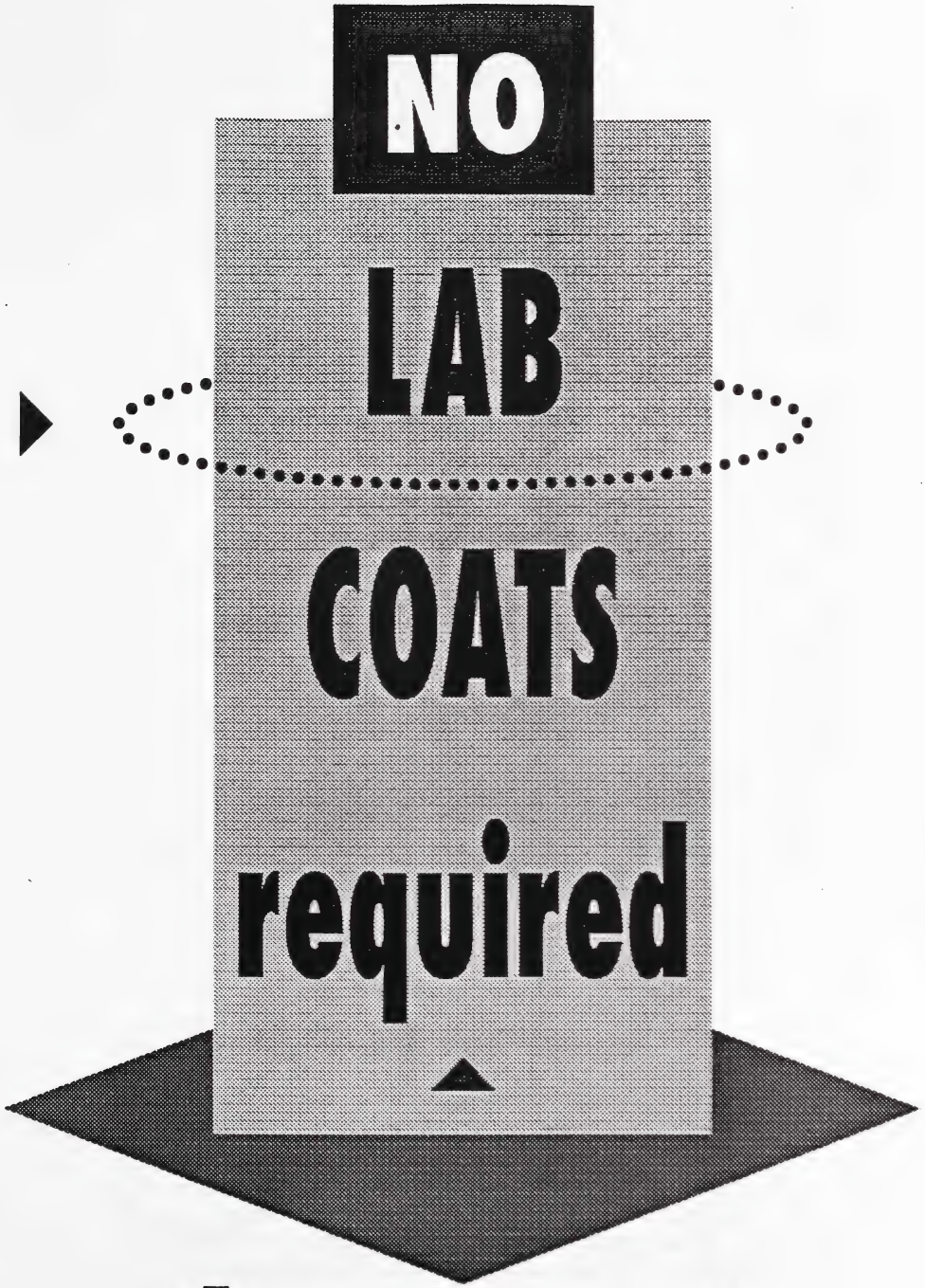

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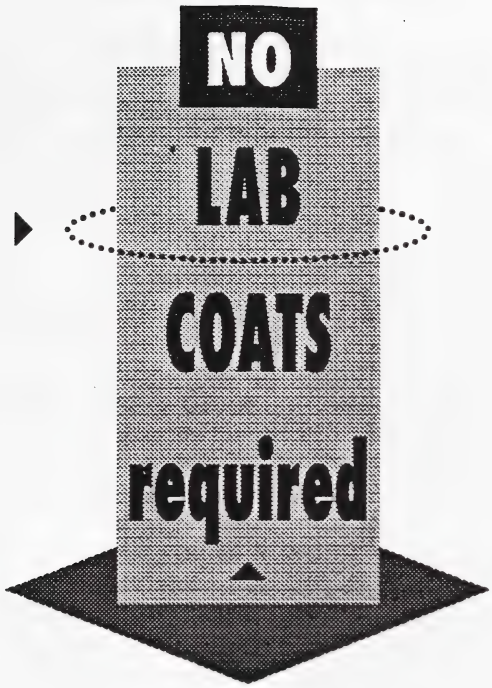
Science Technology & Society



To the Teacher

Science and technology are shaping our world, and Canada depends on the skills of highly trained specialists in every branch of science. This video should encourage students to consider pursuing science-related careers. The video points out how important science is in our everyday lives, and also features profiles of individuals who use science in their daily occupations. Viewers will see that science does not exist as a separate entity, locked away in a laboratory. Nor is science the exclusive domain of people who wear lab coats. Science is part of our world, and if we don't work directly in science, we certainly depend on it. A good solid background in science is invaluable in today's technological society.

Statistics show that while overall university enrollment increased during the last decade, enrollment in the natural sciences, engineering, and computer courses dropped between 20 and 38 per cent, depending on the course. (***Selling Science to Students***, p. 44) Young people represent our future. If Canada is to maintain its standard of prosperity, and its position as a developed nation, we have to ensure that more of our students are excited and challenged by science.

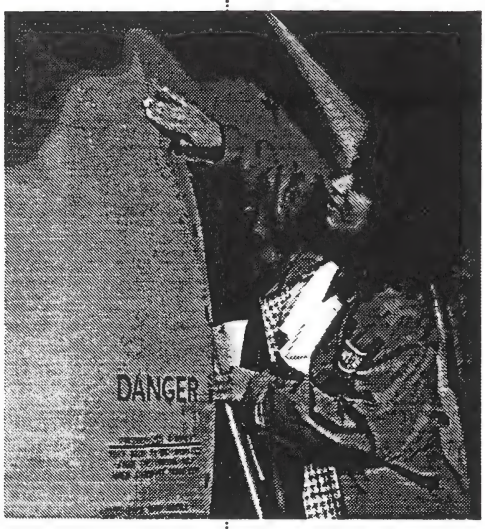
The video is intended for use at the senior high level, and will also be of interest to junior high students.

Overview of No Lab Coats Required

An on-camera host shows viewers that science is an integral part of our daily lives. She introduces several individuals whose occupations involve the application of science or familiarity with scientific principles. These brief profiles take us from a mechanical engineer working on aircraft maintenance to a salesperson who needs a knowledge of science in order to sell a product.

Profile of an Aircraft Structural Engineer

Sunitha Zacharia works as a structural engineer for CAE Aviation, a company involved in the maintenance and overhaul of aircraft. Canada's Department of National Defence is one of CAE's major customers, and Sunitha has worked on a variety of military aircraft, from Hercules transport planes to fighter jets.



Like any other piece of equipment, aircraft are subject to wear and tear and will break down without proper maintenance. The common problems affecting aircraft are corrosion, metal fatigue, and structural cracking. Some repairs to aircraft are routine and can be performed by technicians who follow the appropriate manual. But when damage exceeds what is covered in the manual, the repairs become an engineering decision.

Sunitha Zacharia is called upon when damage to the aircraft exceeds what is routinely covered in the aircraft manual. She assesses the damage, discusses the problem with technicians who do the repairs, and comes up with a plan for repairing the aircraft. She enjoys her work because it offers her the opportunity to be creative and innovative in her designs for repairing the planes.

Carrying out the initial assessment, designing a way to repair the damage and overseeing the repairs are all part of Sunitha's responsibilities. The whole process calls not only for engineering skills and creativity, but also for excellent communications skills. Sunitha is part of a team and depends on the advice and cooperation of those who actually perform the repair work.

Sunitha studied mechanical engineering at university, and learned about aircraft repairs through her work at CAE Aviation. Mechanical Engineering is a very broad field; graduates have to decide where their interests lie, and choose a career which they will find personally rewarding. Sunitha Zacharia chose aircraft maintenance because she has always been fascinated with planes and flying. She finds her work challenging and fulfilling, and is enthusiastic about the opportunities available to students who choose to study engineering. She particularly encourages girls to consider engineering as a career option.

Profile of a Biomechanical Engineer

Kelly James is an engineer in the field of biomechanics. He is working on a new prothesis which will help users to climb stairs more easily, and will make their gait more natural. The process involves extensive research into force and motion, using computer technology and videotapes to precisely calculate movement and pressure.

Although much of Kelly's research takes place in the lab, he also works with the people who will use these prosthetic devices. Kelly's engineering background enables him to make a direct contribution to individuals – improving the quality of life for people who need artificial limbs.

Related Careers

People who enjoy science and mathematics should consider engineering as a career. Engineers are involved in projects ranging from the design of equipment to the construction of bridges. They are problem solvers, always looking for a better way of doing things. Right now, the most sought-after engineering graduates are from these disciplines:

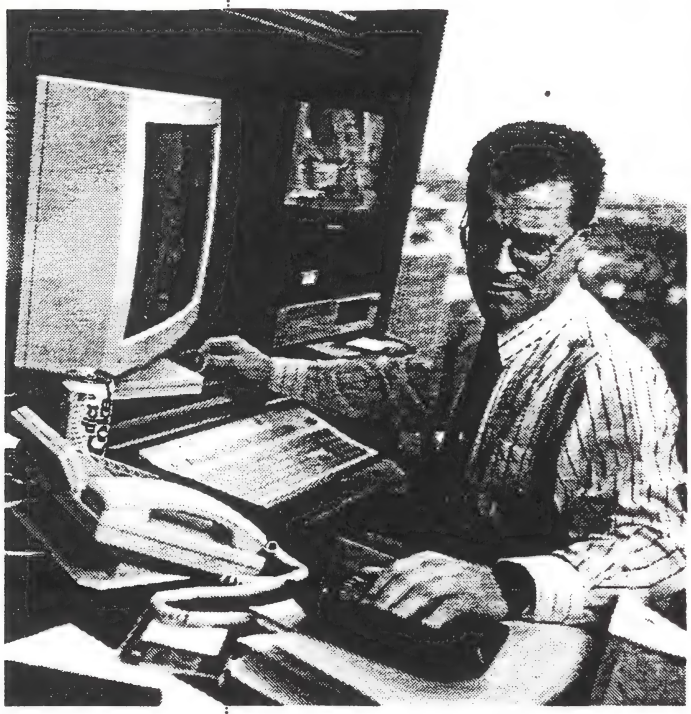
- structural
- geotechnical
- geological
- environmental
- acoustical
- naval
- forensic
- robotics
- electronics
- computer
- aerospace
- aeronautical
- biomedical
- biomechanical
- petroleum

Engineering can be a four year university program, or a five year university co-op program which combines studies with practical experience. In order to become a qualified Professional Engineer, it is necessary to meet the standards set by the provincial association. The candidate must pass examinations set by the association, and complete a two-year Member-In Training program.

A professional engineer's salary compares favourably with that of other professionals, and opportunities for employment are relatively good.

Engineering technology programs are available at technical schools. Different courses pertain to specialized kinds of engineering. The responsibilities and renumeration are not as great as they are for professional engineers, but the course of studies is shorter. Engineering technologists usually have good opportunities for employment in their area of expertise.

Profile of a Communications Consultant



Marvin Polis is an internal communications consultant for a telecommunications company. Although he does not have a degree in science, he works with science every day. Communications today is closely linked with the most advanced computer technology, and the science of communications is constantly evolving.

In the field of telecommunications, lifelong learning is part of the job. Marvin Polis credits high school math and science courses with teaching him the skill he needs most in his job – the ability to think.

Related Careers

Telecommunications is an offshoot of the computer industry, and a university degree can lead to a career in this area. A Bachelor of Science degree in computing science may provide an entry into systems design or data analysis. A degree in mathematics or statistics can also lead to a career in the communications industry.

Technical schools offer more pathways into communications and telecommunications. There are courses in Computer Engineering Technology, Computer Systems Technology, and Telecommunication Engineering Technology. Students who are more attracted to the creative side of communications may be interested in a course in Radio and Television Arts.

Profile of a Sales Representative

Ray Lirette works as a sales representative for a computer company. This is a business where, as Ray puts it, "accelerated change is the status quo". In order to sell highly technical electronic equipment, a sales representative has to have a thorough understanding of the technology, and its capabilities. After all, the sales person has to be at least as well-informed as the buying public, and today's "average" customer is extremely sophisticated and knowledgeable.

Ray Lirette describes his work as being involved in a process of continuous learning and continuous upgrading.

Computer technology isn't the only field where rapid change is the norm. Sales representatives in most other businesses also face constant change – in the products they sell, and in the way they conduct business. No matter what the product, most salespeople are selling a form of science and technology. Whether it is computers, electronic equipment, compact disc players, home entertainment centres, cars, medical equipment, pharmaceuticals, appliances, even processed foods – the advantage of one product over another usually comes down to science. Because we live in a technological society, a solid grounding in science is extremely helpful in the workplace and in daily life.

Sales representatives have to be able to talk science. But then so do consumers. If we want to be informed participants in our society, able to discuss issues intelligently, we need a knowledge of science. Mathematics and science can teach us to think – and help us to understand the world in which we live.

Profile of Two Entrepreneurs

Lois and Ted Hole own and operate a thriving greenhouse business. Ted's university degree in agriculture, combined with Lois' energy and entrepreneurial skills, have produced a winning combination. Although people don't always think of gardening as a scientific activity, horticulture is an extremely complex science.

Horticulture refers to small scale gardening, while agronomy refers to field crops. Both are part of a science that is leading the way in the applications of biotechnology and genetic engineering.

For Lois and Ted Hole, science is a way of life. They continue to improve their own varieties of plants and seeds through the scientific method of experimentation.

Related Careers

The science of growing plants is a huge business in Canada, and there are opportunities here for people who want to put their scientific knowledge to practical use. A university degree in agriculture can lead to many careers besides farming. There are positions with government and private industry at test farms and research centres. The transportation, processing, and marketing of food products are also part of this industry. The business of agriculture is becoming increasingly sophisticated, relying on complex equipment and biotechnology.

Technical colleges may offer courses in Landscape Architectural Technology and Horticulture, as well as various agricultural courses. A course in Forest Technology is another possibility for students interested in biology, biotechnology, and renewable resources.

Suggested Activities

Have students research different careers and each complete a profile of one of the people featured in this video, or of an individual they know who is working in a science-related field. The careers seen in the video are:

- mechanical engineer working on aircraft structure
- biomechanical engineer
- corporate internal communications consultant
- computer sales representative
- greenhouse owner/operator

Information to be gathered could include the following:

- number of years of post-secondary education
- courses of study (e.g., general science degree first, followed by specialization)
- qualifying examinations required (e.g., to become a Professional Engineer)
- demand for graduates in this field
- average starting salary
- average salary after ten years
- job security
- opportunities for advancement
- ratio of males to females
- quality of work environment
- level of job satisfaction
- type of individual who may be attracted to this work

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